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# Development and Testing of a Wastewater Recycler and Heater

CHEMTRIC, Inc, Rosemont, Ill

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Two units were fabricated - one for the U. S. Army Medical R & D Command, and one for the National Aeronautics and Space Administration. The Army unit was tested for 38 days with real laundry water, and 21 days with a synthetic brine water that simulates concentrated wastewater from a hospital. The results achieved with real laundry water were as expected - i.e., neutral water with very low solids and low turbidity; however, the presence of organic volatiles and ammonia in the synthetic brine water caused the water recovered during the second test to be unacceptable - thus indicating that pretreatment and/or additional processing is necessary when these contaminants are present.

An economic assessment is also included in the report.

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EPA-600/2-76-289
December 1976

# DEVELOPMENT AND TESTING OF A WASTEWATER RECYCLER AND HEATER

by

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EPA Contract No. 68-03-0436

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This study was conducted
in cooperation with
National Aeronautics and Space Administration
Department of Housing and Urban Development
U.S. Army Medical R & D Command
U.S. Coast Guard

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
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# FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The work described here presents the design and evaluation of an appliance intended for use in applications where it is economical to recover usable hot water from wastewater without the expenditure of additional energy.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

# ABSTRACT

This report describes the design, fabrication and testing of a distillation unit that utilizes the flash evaporation and vapor compression processes to recover usable hot water from contaminated wastewater. This unit does not require the use of any expendable materials, and it is capable of recoverying more than 96% of the available wastewater while using less than 80 watt-hours of energy per liter of recovered water.

Two units were fabricated--one for the U.S. Army Medical R & D Command, and one for the National Aeronautics and Space Administration. The Army unit was tested for 38 days with real laundry water, and 21 days with a synthetic brine water that simulates concentrated wastewater from a hospital. The results achieved with the real laundry water were as expected-- that is, neutral water with very low solids and low turbidity; however, the presence of organic volatiles and ammonia in the synthetic brine water caused the water recovered during the second test to be unacceptable--thus indicating that pretreatment and/or additional processing is necessary when these contaminants are present.

This report also includes an economic assessment that concludes that this type of unit is advantageous for use in areas where fresh water must be transported by vehicles. To justify the use of this appliance in metropolitan areas, however, a lower cost design and mass production techniques are required.

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# LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| $A_o$ | Outside area of insulation jacket. |
| $A_1$ | Outside area of processor tank. |
| $C_p$ | Isobaric heat capacity. |
| D | Compressor displacement. |
| $D_o$ | Outside diameter of condenser coil. |
| $D_i$ | Inside diameter of condenser coil. |
| $h_1$ | Enthalpy of saturated vapor at temperature $T_1$. |
| $h_2$ | Enthalpy of saturated vapor at temperature $T_2$. |
| $h_3$ | Enthalpy of saturated vapor at temperature $T_3$. |
| $h_f$ | Enthalpy of saturated liquid at temperature $T_1$. |
| $h_f'$ | Enthalpy of saturated liquid at temperature $T_e$. |
| $h_o$ | Enthalpy of influent. |
| $H_c$ | Heat transfer coefficient due to convection. |
| $H_r$ | Heat transfer coefficient due to radiation. |
| K | Compressor slip coefficient. |
| k | Thermal conductivity of condenser coil material. |
| k' | Thermal conductivity of insulation material. |
| L | Length of condenser coil. |
| M | Compressor productive speed. |
| N | Compressor shaft speed. |
| n | Number of coils in condenser. |
| n' | Number of spirals in each condenser coil. |
| $P_1$ | Evaporator saturation pressure. |
| $P_2$ | Condenser saturation pressure. |
| $P_e$ | Liquor pressure at exit of condenser coil. |
| $q_L$ | Heat loss from processor. |
| $R_L$ | Condenser coil heat transfer resistance. |
| $R_V$ | Condenser coil vapor side heat transfer resistance. |

Abbreviations and Symbols Continued.

| | |
|---|---|
| $R_w$ | Condenser coil wall heat transfer resistance. |
| $r_o$ | Minimum spiral radius of condenser coil. |
| S | Compressor slippage rpm. |
| $T_a$ | Ambient temperature. |
| $T_1$ | Vapor temperature in evaporator. |
| $T_2$ | Vapor temperature at compressor discharge. |
| $T_3$ | Vapor temperature in condenser. |
| $T_e$ | Liquor temperature at exit of condenser coil. |
| $T_m$ | Mean temperature $(T_e+T_1)/2$. |
| $T_s$ | Surface temperature of insulation jacket. |
| t | Condenser coil wall thickness. |
| U | Condenser coil overall heat transfer coefficient. |
| V | Liquor velocity in condenser coil. |
| $\dot{W}_s$ | Compressor motor shaft power. |
| $\dot{W}_s'$ | Recycle pump motor shaft power. |
| x | Fraction vapor content in recycle liquor. |
| y | Thickness of insulation jacket. |
| $\Delta P$ | Vapor pressure rise across compressor. |
| $\Delta P'$ | Liquor pressure drop across condenser coil. |
| $\Delta T_m$ | Mean temperature difference $(T_3-T_m)$. |
| $\Delta r$ | Condenser coil spiral spacing. |
| v | Vapor specific volume. |
| v' | Liquor specific volume. |
| $\dot{\omega}$ | Recovery rate. |
| $\dot{\omega}'$ | Recycle liquor flow rate. |
| $\theta_{lm}$ | Log mean temperature difference. |
| $\gamma$ | Ratio of specific heats. |
| $\eta_p$ | Compressor polytropic efficiency. |
| $\eta_v$ | Compressor volumetric efficiency. |
| $\eta_m$ | Compressor motor efficiency. |
| $\eta'$ | Recycle pump hydraulic efficiency. |

# ACKNOWLEDGMENTS

This project was carried out by Victor Guarino (Project Engineer) under the direction of Robert Bambenek (President of CHEMTRIC, Inc.). Walter Jasionowski served as chemical engineering consultant throughout the program and provided valuable guidance in setting up the water quality evaluation tests. All of the day-to-day testing of the equipment and the in-house water analyses were conducted by Andrew Murman (Technician) and Reid Urban (Biochemist); their work is gratefully acknowledged. The detailed chemical analysis of the product water for trace metals, ions and organics were carried out by the Nalco Chemical Company, Analytical Services Division.

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## SECTION I

## INTRODUCTION

The National Environmental Research Center (NERC) of the Environmental Protection Agency (EPA) awarded contract 69-03-0436 to CHEMTRIC Incorporated on 16 April 1974 for the "development and testing of a wastewater recycler and heater". This report summarizes the technical work performed under that contract; the installation, operation and maintenance requirements of the Recycler/Heater are described in the Appendices.

The Recycler/Heater utilizes previously developed spacecraft technology to recover usable hot water from wastewater; it can be used in domestic, industrial, military and marine applications. Consequently, EPA contract 68-03-0436 was jointly monitored and funded by five Federal Agencies -- namely, the Environmental Protection Agency, the National Aeronautics and Space Administration, the Department of Housing and Urban Development, the U.S. Army, and the U.S. Coast Guard.

### Background

The continuously increasing use of fresh water from public water supplies and the attendant increase of wastewater has created two major problems: conserving our limited fresh water reserves, and stablizing the burden on our limited capacity water and wastewater treatment systems. Since domestic water usage accounts for nearly 50% of the water supplied from public utilities, long term conservation policies should have an important impact on the stabilization of per capita costs to build and operate these systems.

Methods of reducing home water consumption have been analyzed.[1,2,3] These studies, sponsored by the Environmental Pro-

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1. Bailey, James R.; Benoit, Richard J.; Dobson, John L.; Robb, James M. and Wallman, Harold, A Study of Flow Reduction and Treatment of Waste Water from Households. General Dynamics, Electric Boat Division, Groton, Conn. (1969)
2. Cohen, Sheldon and Wallman, Harold, Demonstration of Waste Flow Reduction from Households. General Dynamics, Electric Boat Division, Groton, Conn. (1974)
3. Chan, Michael L., Wastewater Flow Reductions Study, Energy Resources Co., Inc. Cambridge, Mass. (1975)

tection Agency, focus primarily on the use of water-saving plumbing fixtures, public education, metering and pricing schemes, and building codes. Cohen and Wallman[2] have evaluated a pilot recycle system to reuse bath and laundry water for toilet flushing and lawn watering. This system used filtration and chemical disinfection and did not recover hot water.

Water recycling has been used for many years in industrial plants to reduce pretreatment costs and/or concentrate wastewater for disposal or mineral recovery. In Windheock, South Africa, 30% of the domestic water supply is recovered from the sewage treatment plant.[4] Thus, large-scale recycling has already been justified in certain applications and areas. Now the question is: How and where can water recycling be justified on a household-size scale?

Since 1958, a relatively large amount of research has been performed on processes that appear to be suitable for recycling water onboard manned spacecraft. The most developed system utilizes reverse osmosis to recover usable water from expended wash water, and compression distillation followed by adsorption filtration to recover potable water from pretreated urine, urinal flush water, humidity condensate, and the reverse osmosis concentrate.[5] The compression distillation unit, which CHEMTRIC developed under several NASA contracts, was selected because it requires less energy and less make-up water than the other processes considered for spacecraft.

In 1971, using technology acquired under NASA contracts, CHEMTRIC personnel devised the compression distillation unit illustrated in Figure 1. The unique feature of this design is its ability to first use the input energy to distill water from wastewater, and finally recover most of this energy as sensible heat in the product water. Thus, the cost to operate this unit should not be any greater than an equivalent-capacity, electrically operated water heater. Other advantages of this design are:

A. Wastewater is processed at 165°F to assure the delivery of sterile product water.

B. Flash evaporation, instead of submerged evaporation surfaces, is used to minimize the effects of dissolved solids on distillation rate and thereby recovered a high percentage of the available water.

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4. Weinstein, Richard, H., Water Recycling for Domestic Use, Astronautics & Aeronautics, March 1972, 44-51.
5. Ziegler, Leon, Water and Waste Management System Design for a Space Station Prototype, ASME Publication 72-ENAv-8, August 1972.

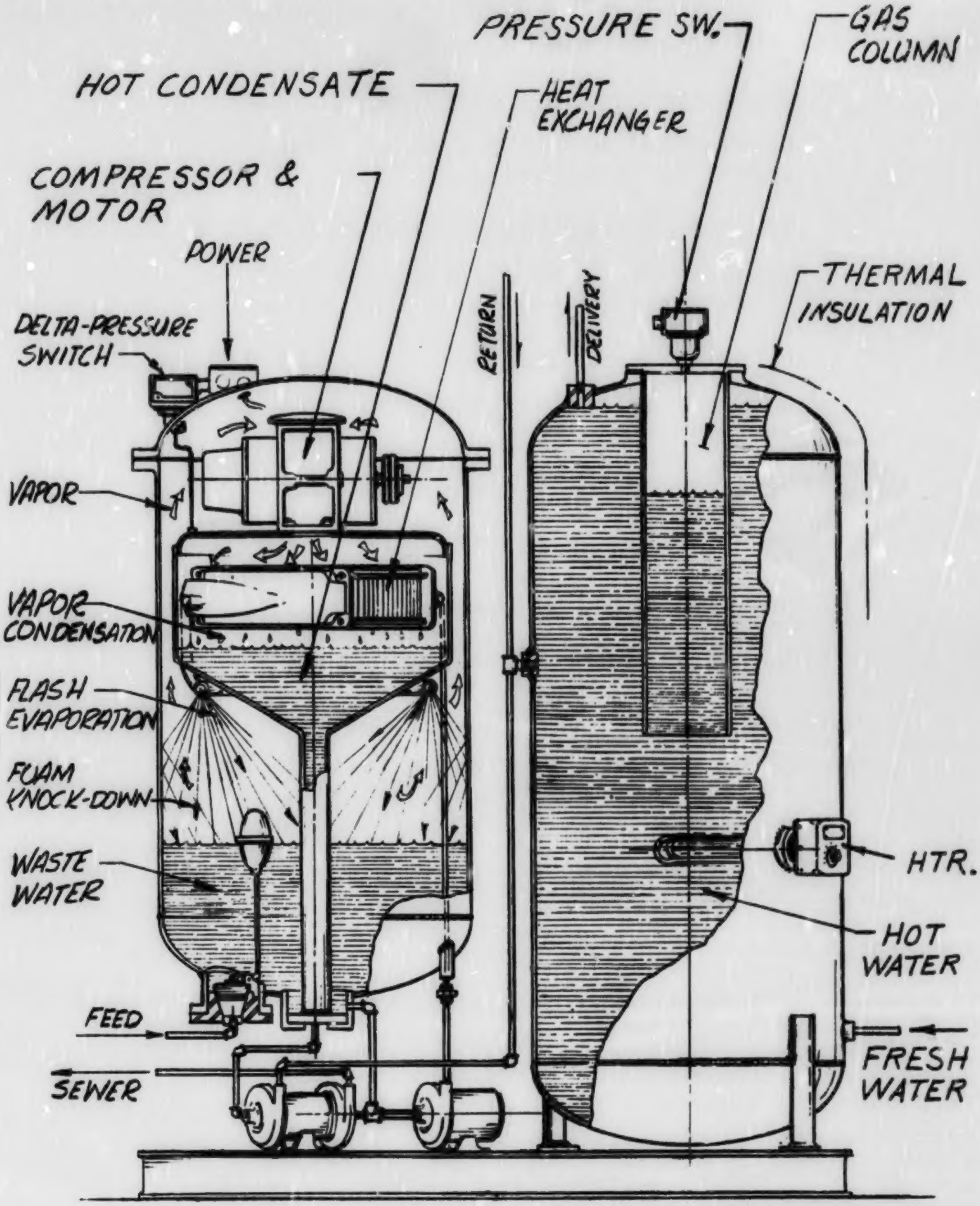

PRESSURE SW.
GAS COLUMN
HOT CONDENSATE
HEAT EXCHANGER
COMPRESSOR & MOTOR
POWER
THERMAL INSULATION
RETURN
DELIVERY
DELTA-PRESSURE SWITCH
VAPOR
VAPOR CONDENSATION
FLASH EVAPORATION
FOAM KNOCK-DOWN
WASTE WATER
HTR.
HOT WATER
FEED
FRESH WATER
SEWER

Figure 1. PROPOSED WATER RECYCLER/HEATER

Subsequent to the conception of the unit in Figure 1, CHEMTRIC proposed the development of this system to the following agencies for the reasons stated.

Environmental Protection Agency (EPA)

Recovery of usable hot water from domestic wastewater.

National Aeronautics & Space Administration (NASA)

Utilization of NASA technology for domestic applications.

Department of Housing & Urban Development (HUD)

Recovery of usable hot water from domestic wastewater.

U.S. Army Medical R&D Command (AMRDC)

Recovery of usable hot water from field hospital wastewater.

U.S. Coast Guard (USCG)

Recovery of shower wastewater for reuse as laundry water.

Since all of these agencies were found to be interested in the proposed system, they met with CHEMTRIC personnel at NASA Headquarters on 17 October 1973. At this meeting it was agreed that they would jointly fund an EPA contract with CHEMTRIC for the development of the proposed system. Subsequently, CHEMTRIC was awarded EPA contract 68-03-0436.

## Scope of Work

The objective of this program was to design, fabricate and evaluate a prototype unit which is capable of recoverying up to 6 gallons per hour of usable 165°F water from room-temperature wastewater, using no more than 1800 watts of electrical power. This capacity was selected because it (1) corresponds to the smallest, commercially-available, domestic water heater, and (2) equals the highest distillation rate attainable at 165°F with the smallest vapor compressor used by CHEMTRIC for spacecraft water recovery systems.

Before the detail design drawings were prepared, the basic design was analyzed mathematically to determine the combination of independent parameters which would yield a design requiring no more than 1800/6, or 300 watt-hours per gallon (79 watt-hours per liter). When this was determined, the detailed design drawings were prepared.

Two units were fabricated so that the AMRDC and at least one other agency would each have a unit to evaluate at their facilities. The second unit was eventually assigned to the NASA Langley Research Center, but delivered on a loan basis to the Naval Ships R&D Center at Annapolis for evaluation as a concentrator for shipboard wastes.

Evaluation of the device was primarily concerned with a quanitative analysis of the recovered water and the thermodynamic performance of the system. To this end two wastewater streams were processed - i.e., real laundry water and a synthetic waste which simulates the brine from the AMRDC Medical Unit, Self contained, Transportable (MUST) hospital water treatment system. It was originally proposed that shower water and sink water would also be processed, but hardware development problems delayed the testing phase and time did not permit evaluations with these waste streams. It was recognized, however, that the simulated brine waste stream was a synthetic composite of concentrated laundry, shower, and sink wastes. For all test runs, system data and water samples for chemical and physical analysis were collected at regular intervals. All the detailed results are presented in this report under Section VI. In Sections IV and V the detailed design analysis and description of the prototype design are presented.

## SECTION II

## CONCLUSIONS

The results of this program have demonstrated the feasibility of an automatic and self-contained appliance that can recover and store usable hot water from waste laundry water, using essentially the same amount of energy as an equivalent-capacity water heater. It has been shown by extended evaluation tests with a waste stream of real laundry water that this unit is capable of recovering sterile hot water at a steady state rate of 22.7 liters/hour (6 gph) with a specific energy draw of 79 watt-hours/liter (299 watt-hours/gal), without the use of any expendable chemicals. It has also been shown by extended evaluation tests with a feed that simulates hospital wastewater preconcentrated by ultrafiltration and reverse osmosis that this unit can increase the solids concentration of a waste water from less than 2% to at least 29.3%.

When real laundry water is processed, the product water is typically neutral with a turbidity below 10 Jtu and has COD and total dissolved solids levels below 75 mg/l. When the feed stock contains a large quantity of volatile liquids, which the hospital waste simulant contained, low boiling point volatiles such as ammonia and the alcohols will carry over and dissolve in the product water. In this case, therefore, pretreatment and/or post-treatment is required to obtain usable hot water.

The results of a manufacturing cost analysis have shown that a conservative annual cost (that is, a maximum annual cost) of this appliance is $717 per year. This is based on a production quantity of 10,000 units per year, a 20-year operational life, and an interest rate of 8%. Since this appliance could typically conserve 166,000 liters (44,000 gallons) per year of potable water per household, economic feasibility is based on comparison of unit cost per year to savings in water and sewer costs. It has shown that at the present time (1974 data), these savings are typically under 200 dollars in metropolitan areas across the United States (except in isolated cases such as the outskirts of Fairbanks and Anchorage where the savings could be as high as $2,100 per Year). Economic feasibility therefore is not demonstrable at present on a large scale. However this analysis does point out that should water cost increase in the future by a factor of 4 or more, or if the cost of the appliance is reduced by a factor of 4 or more to yield a "break-even" situation, a viable demand for household water recovery with the appliance would be possible.

decrease

## SECTION III

## RECOMMENDATIONS

Upon completion of the development tests, the two prototype units constructed as part of this development program were shipped to the following locations for further evaluation of their performance when processing various wastewaters.

Unit #1:

U.S. Army Medical Bioengineering Laboratory
Fort Detrick, Frederick, Maryland

Unit #2:

Naval Ships R&D Center
Annapolis, Maryland

The tests planned at Annapolis, with preconcentrated real laundry water, should be continued until the solids concentration causes the recovery rate and/or the water quality to fall below the Navy's acceptable level for shipboard use. With these data it will be possible to design a shipboard unit that has the required overall performance.

The tests planned at Fort Detrick with simulated hospital wastewater should be performed to determine whether processing real brine yields ammonia and organic volatiles, and if it does, whether acidifying and degassing reduce the quantity of these contaminants to an acceptable level.

A cost reduction study is recommended to determine the design that yields the lowest "installed cost". For example, the prototype assemblies contain an integrated weldment assembly of the processor tank, sump tank and hot water storage tank; separation of these tanks would facilitate transportation and allow the use of a standard storage tank. The tanks could be fastened together after installation to maintain the advantage of conduction between the two tanks (i.e., only one heating element required). A value engineering study would reveal how each item should incorporate only those functions and materials necessary and how these might be arranged differently to effect cost reductions in the overall appliance design.

In addition to a cost reduction study, it is necessary to set up the hot water recovery appliance in a real household situation so that user reactions can be fully integrated into the design, and water balances and cycle times can be monitored. In this situation, sink water and/or shower water could also be processed to provide the make-up wash water.

Finally, the Recycler/Heater should be considered for applications where its ability to concentrate solutions to more than 30% solids yields additional cost savings. Examples of this are applications where the concentrate must be stored and transported to a storage facility or disposed by means of incineration and/or pyrolysis.

# SECTION IV

## DESIGN ANALYSIS

This section presents the thermodynamic, fluid mechanical, and heat transfer analysis which preceded the hardware design.

### Conceptual Arrangement

Figure 2 shows a sketch of the system concept. The system is comprised of three basic elements--a processor tank, a sump or wastewater holding tank, and a hot water storage tank. The processor tank, which is the primary element and the subject of this analysis, incorporates the processes of flash evaporation and compression distillation. The sump tank is used to control the feed of waste water into the processor and also serves as a phase separator, as described in Section V. The storage tank is used to hold the hot product water from the processor and to maintain the product water temperature when the processor is shut down.

Referring to Figure 2, the system operates as follows. Wastewater enters the sump which contains a float control to automatically start the processor when the sump is filled (and automatically turn the processor off when empty). From the sump it enters the evaporator section of the processor tank on demand via a liquid level control of the feed valve. The fresh feed is mixed with previously concentrated liquor, and the solution is continuously circulated in the recycle loop via a centrifugal pump (recycle pump). It is seen that the recycle pump takes the liquor from the evaporator shell and passes it through a heat exchanger coil located within the condenser shell. The heated liquor is then returned to the evaporator through a manifold of spray nozzles where a small portion is flashed into water vapor and the remainder returned to the recycle loop to become more concentrated. The vapor is simultaneously drawn into the condenser shell via a small positive displacement compressor which raises its pressure and temperature. Within the condenser shell the vapor is directed over the heat exchanger coil containing the recycle liquor at a lower temperature. The vapor condenses on the coil and the latent heat is transferred back to the evaporator to continue the evaporation process. The hot condensate is removed from the condensor shell and transferred to the storage tank via a small positive displacement pump (condensate or product water pump). When the pressure in the storage tank reaches a maximum the processor is automatically shut down. A thermostatically-controlled heater then maintains the temperature of the stored

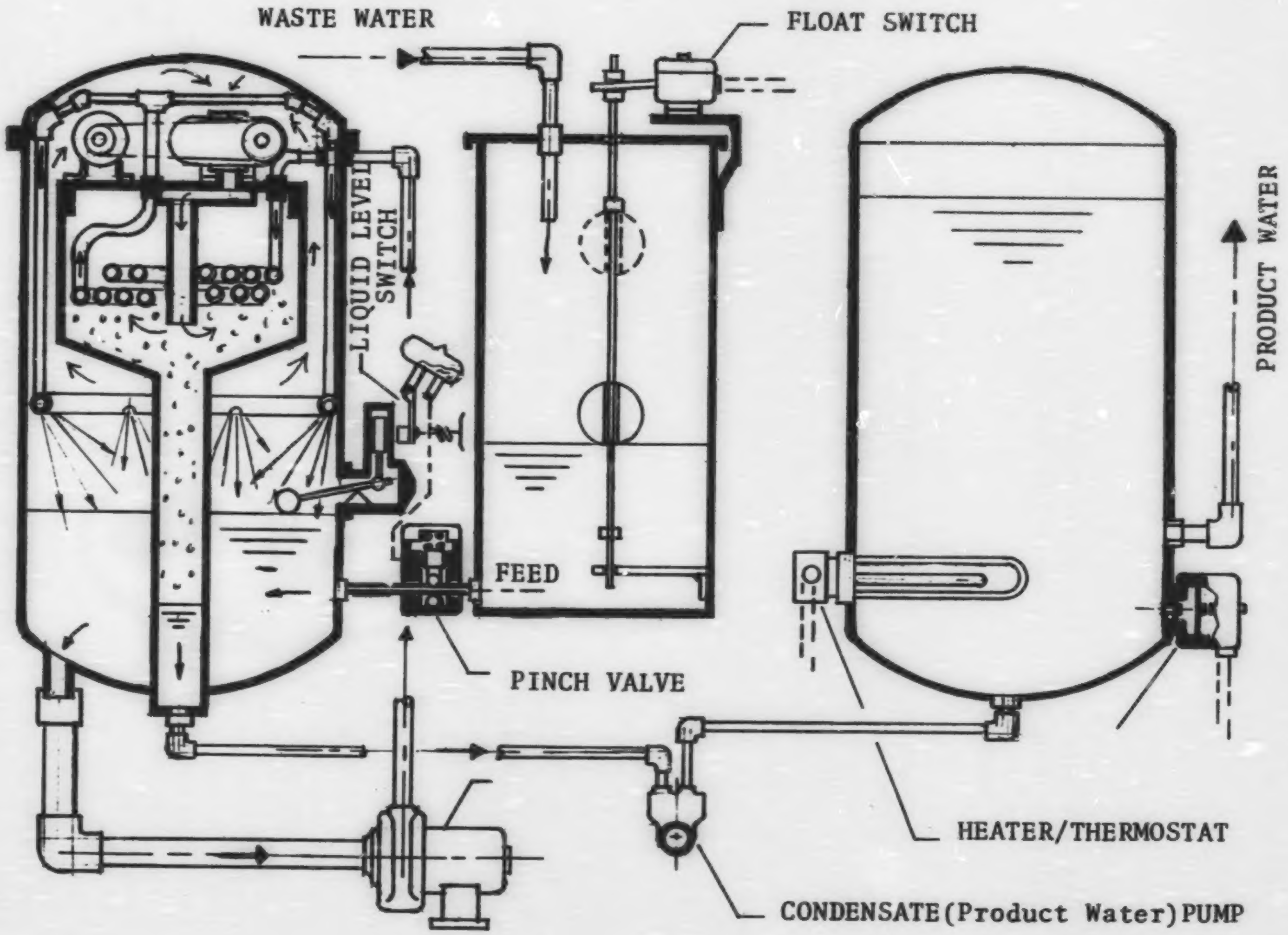

WASTE WATER
FLOAT SWITCH
LIQUID LEVEL SWITCH
PRODUCT WATER
FEED
PINCH VALVE
HEATER/THERMOSTAT
CONDENSATE(Product Water)PUMP

Figure 2 CONCEPTUAL ARRANGEMENT OF RECYCLER/HEATER

water at the pasteruization temperature, which is also the saturation temperature of the condensate in the processor.

The unique feature of the processor is its ability to recycle the latent heat of condensation, and at the same time concentrate the waste stream.

## Design Requirements

The fundamental design philosophy was to incorporate the system concept presented in Figure 2 into a practical design for home use. To this end the following requirements were stipulated.

1. The processing rate should be 6 gph, comparable to a domestic hot water heater.
2. The condenser temperature should be at the pasteurization temperature, 165°F, to avoid biological contamination.
3. The power required to operate the processor should be essentially the same as the power to run an electric water heater of the same recovery rate, which for a 100°F temperature rise is approximately 1600 to 1800 watts.
4. The physical dimensions of the processor should be such that the overall width is smaller than a standard residential door opening, 71 cm (28 in), and the overall height, including head space for maintenance is smaller than a standard residential basement ceiling height, 213 cm (84 in).
5. The heat exchanger should be a compact design consisting of two horizontal spirals of copper tubing which are series wound. The outside diameter of the spirals should not exceed 48 cm (19 in).
6. The exit temperature of the recycle liquor passing through the heat exchanger should be 164°F - that is, one degree less than the condenser temperature.
7. The vapor compressor should be a Gardner-Denver Model 2PDR4, or a Sutorbilt Model 2LB. These compressors have the respective displacements of 0.033 and 0.035 cubic feet per revolution, and both have a volumetric efficiency near 90% with air at standard conditions.
8. The recycle pump should be a centrifugal pump with an efficiency near 50% and a net positive suction head requirement (NPSH) not more than two feet.

These design requirements together with a thermodynamic model of the vapor compression and flash evaporation processes allowed a complete set of calculations to be performed. The results of these calculations were used to complete the detailed mechanical design of the processor.

## Thermodynamic Model

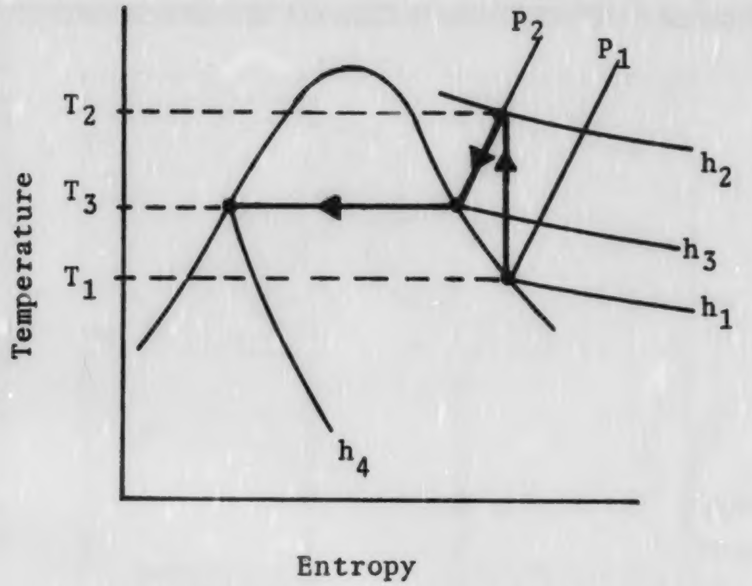
For the purpose of performing the numerical calculations necessary in the mechanical design of the processor a thermodynamic model was described by using the temperature - entropy (T-S) diagrams shown in Figures 3 and 4. In Figure 5, a schematic of the processor shows where, within the mechanical system, the thermodynamic variables in the T-S diagrams occur. Following the T-S diagram in Figure 3, vapor in the evaporator at the saturation temperature $T_1$ and pressure $P_1$ is drawn into the compressor at a recovery rate $\dot{\omega}$ , where its temperature and pressure are raised via an isentropic compression to the superheat temperature $T_2$ at condenser pressure $P_2$. The compressor discharges the vapor at temperature $T_2$ directly into a transfer pipe where it passes to the bottom of the condenser shell and then upward past the heat exchanger coils. Counter-flowing water droplets dripping off the cooling coils dissipate the superheat $(h_2 - h_3)$ so that the vapor temperature is reduced to the saturation temperature $T_3$ at condenser pressure $P_2$. The amount of re-vaporization that occurs is balanced by the amount of condensation that occurs on the walls of the condenser shell. The log-mean temperature differential $\theta_{lm}$ necessary to transfer the latent heat of condensation $(h_3 - h_4)$ is generated by the liquor flow $\dot{\omega}'$ in the condenser coil. The liquor enters the coil at temperature $T_1$, and exists the coil at temperature $T_e$, which is one degree less than $T_3$. The log-mean temperature difference, then, is:

$$\theta_{lm} = \frac{T_e - T_1}{ln(T_3 - T_1)} = \frac{164 - T_1}{ln(165 - T_1)} \qquad (1)$$

Following the T-S diagram in Figure 4, the liquor at temperature $T_e$, undergoes a constant enthalpy expansion (throttling process) through a manifold of spray nozzles. The expansion occurs between states $T_e$, $P_e$ and $T_1$, $P_1$. The nozzles are located within the evaporator shell in the space above the liquor reservoir to allow the vapor to separate from the liquid. Energy transferred (heat) to the liquor, $(h_{f'} - h_f)\,\dot{\omega}'$ , just balances the latent heat of condensation $(h_3 - h_4)\,\dot{\omega}$ .

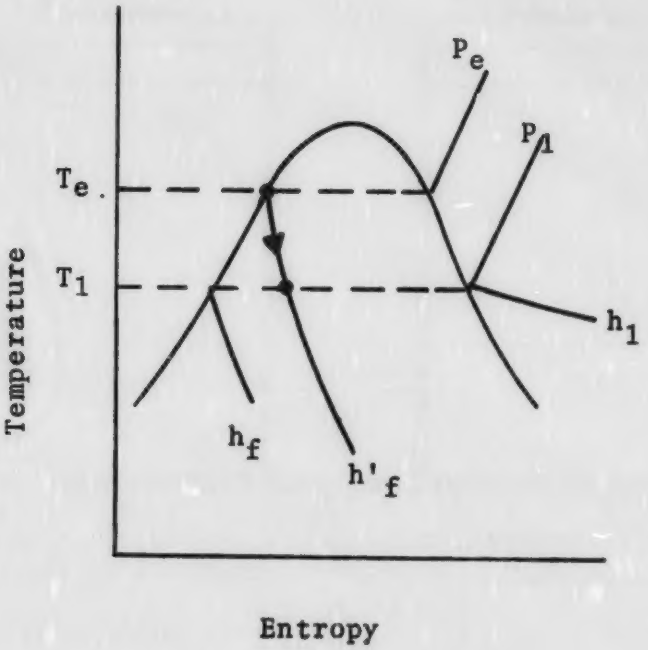
In the real system heat losses, $h_L$, occur through the evaporator shell to the environment so that the heat rate balance is:

$$\dot{\omega}' h'_f = \alpha h_1 \dot{\omega} + h_f \dot{\omega}' + h_L \qquad (2)$$



P2
P1
T2
h2
T3
h3
T1
h1
Temperature
h4
Entropy

Figure 3 T-S DIAGRAM FOR VAPOR COMPRESSION



Pe
P1
Te
T1
h1
Temperature
hf
h'f
Entropy

Figure 4 T-S DIAGRAM FOR FLASH EVAPORATION

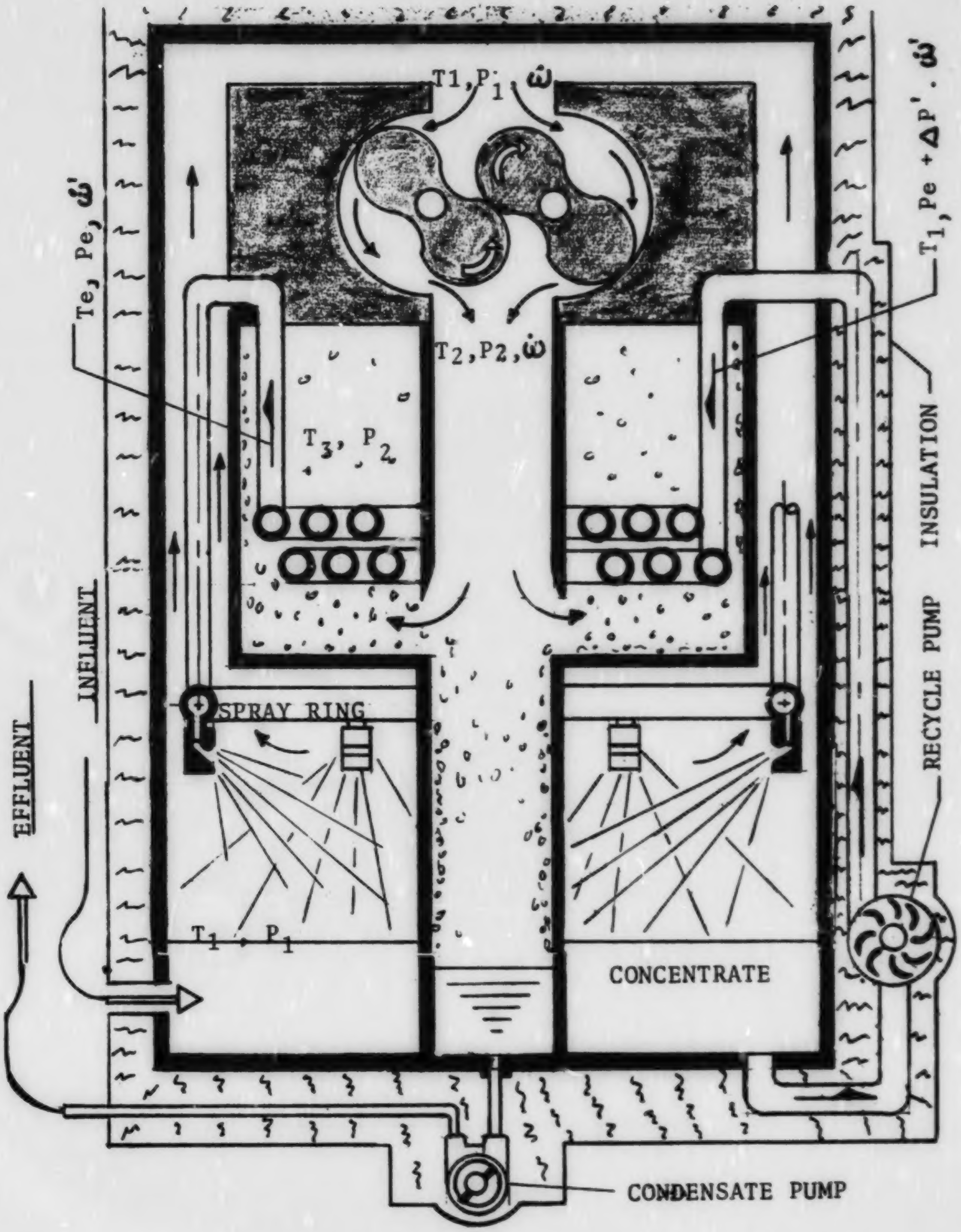

T1,P1,ω̇
Te, Pe, ω̇'
T1, Pe +ΔP', ω̇'
T2,P2,ω̇
T3, P2
INSULATION
RECYCLE PUMP
INFLUENT
EFFLUENT
SPRAY RING
T1, P1
CONCENTRATE
CONDENSATE PUMP

Figure 5 SCHEMATIC ARRANGEMENT OF PROCESSOR

In order to maintain the rate balance without an external heat source the processor is insulated so that the following relationship applies.

$$q_L = (h_2 - h_3)\dot{\omega} - \frac{1-\eta_m}{\eta_m} W_s - (h_1 - h_0) x \dot{\omega}' \tag{3}$$

| | | | |
|---|---|---|---|
| Rate of Heat Loss | Rate of Superheat | Rate of Motor Heat | Rate of Heat Transfer to Influent |

Since the vapor compression ratio is small the superheat $(h_2 - h_3)$ is small; also, the feed stock flow $x\dot{\omega}'$ is very small compared to the recycle flow $\dot{\omega}'$ . Therefore, in the model the heat loss is balanced primarily by the motor heat generation. That is to say, in the thermodynamic model a heat rate balance occurs such that the rate of heat generated by the motor just balances the rate of heat loss to the environment. It is this heat balance that determines the actual steady state operating temperatures of the processor.

By virtue of the thermodynamic model and design requirements described above, a detailed quantitative analysis was conducted in order to arrive at the optimum design point. In the next Section the optimum design point is shown to be the evaporator saturation temperature, $T_1$, at which the power required to operate the processor is minimal. By proper mechanical design, the actual steady state operating point can be made to closely coincide with the optimum design point.

## Calculations

The optimum design point for operation of the processor is found by computing the vapor compressor and recycle pump power requirements as a function of evaporator vapor temperature $T_1$. Figure 6 presents a graph of the numerical results. It is seen that for a fixed condenser temperature $T_3$ the compressor shaft power is inversely related to the evaporator temperature $T_1$ - but the recycle pump shaft power varies directly with temperature $T_1$. Therefore, for a given heat exchanger tube diameter there is a saturation temperature, $T_1$, which yields a minimum power requirement. At this point the compressor shaft speed is also specified. The following steady state equations were used to derive the optimization curve in Figure 6.

The compressor power is related to the evaporation temperature via the relationship:

$$\dot{W}_s = \frac{0.293\, C_p (T_2 - T_1)\, \dot{\omega}}{\eta_v \eta_i}, \text{ watts} \tag{4}$$

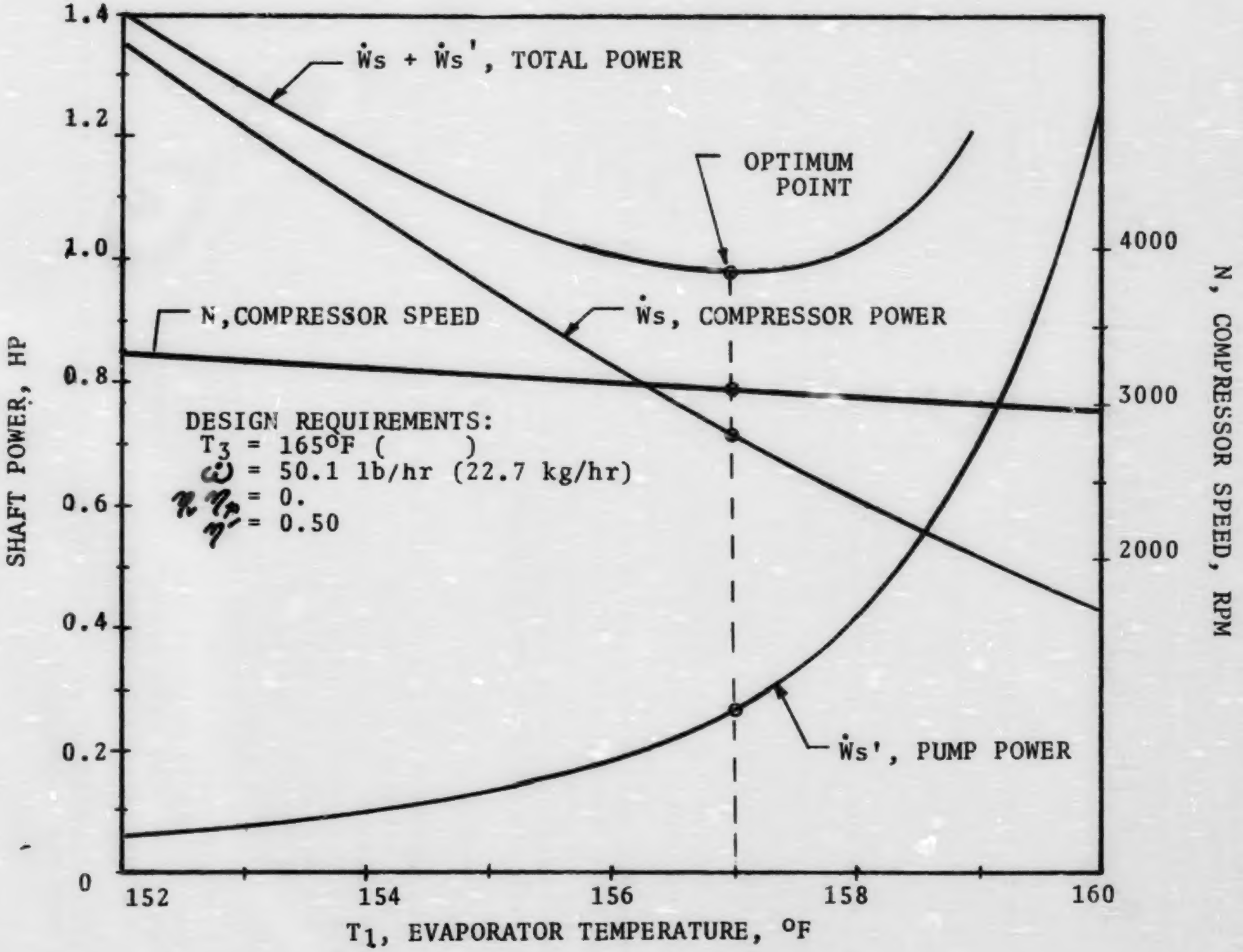


Figure 6 RESULTS OF DESIGN CALCULATIONS

The shaft power, Ws, is dependent on the shaft speed, N, and again dependent on temperature $T_1$ through the volumetric efficiency

$$\eta_v = \frac{\dot{\omega} v}{60 N D} \tag{5}$$

where the required shaft speed, N, is shown to be temperature $T_1$ dependent by the following relationship.

$$N = \frac{\dot{\omega} v}{60 D} + \text{SLIPPAGE}, \ \text{rpm} \tag{6}$$

For lobe-type rotary compressors the slippage is constant for a given lobe diameter and compression ratio, and can be expressed in terms of rpm by

$$S = K \sqrt{\frac{0.075\,\gamma}{3.5(\gamma - 1)}\, v\,\Delta P}, \ \text{rpm} \tag{7}$$

where the slip coefficient, K, is the slippage for air at standard inlet conditions (14.7 psia, 70$^{\circ}$F) and unit pressure difference occurs across the compressor. Values of K are given by the compressor manufacturer.

The recycle pump shaft HP requirement is related to the evaporator temperature via the relationship

$$\dot{W}_s' = \frac{7.27\, v' \Delta P' \dot{\omega}'}{\eta'} 10^{-5}, \ \text{HP} \tag{8}$$

in which the pump capacity, $\dot{\omega}'$, is coupled to the compressor capacity, $\dot{\omega}$, by the relationship

$$\dot{\omega}' = \frac{\dot{\omega}}{x} \tag{9}$$

where the fraction vapor content, x, is determined from the constant enthalpy expansion through the spray nozzles - that is,

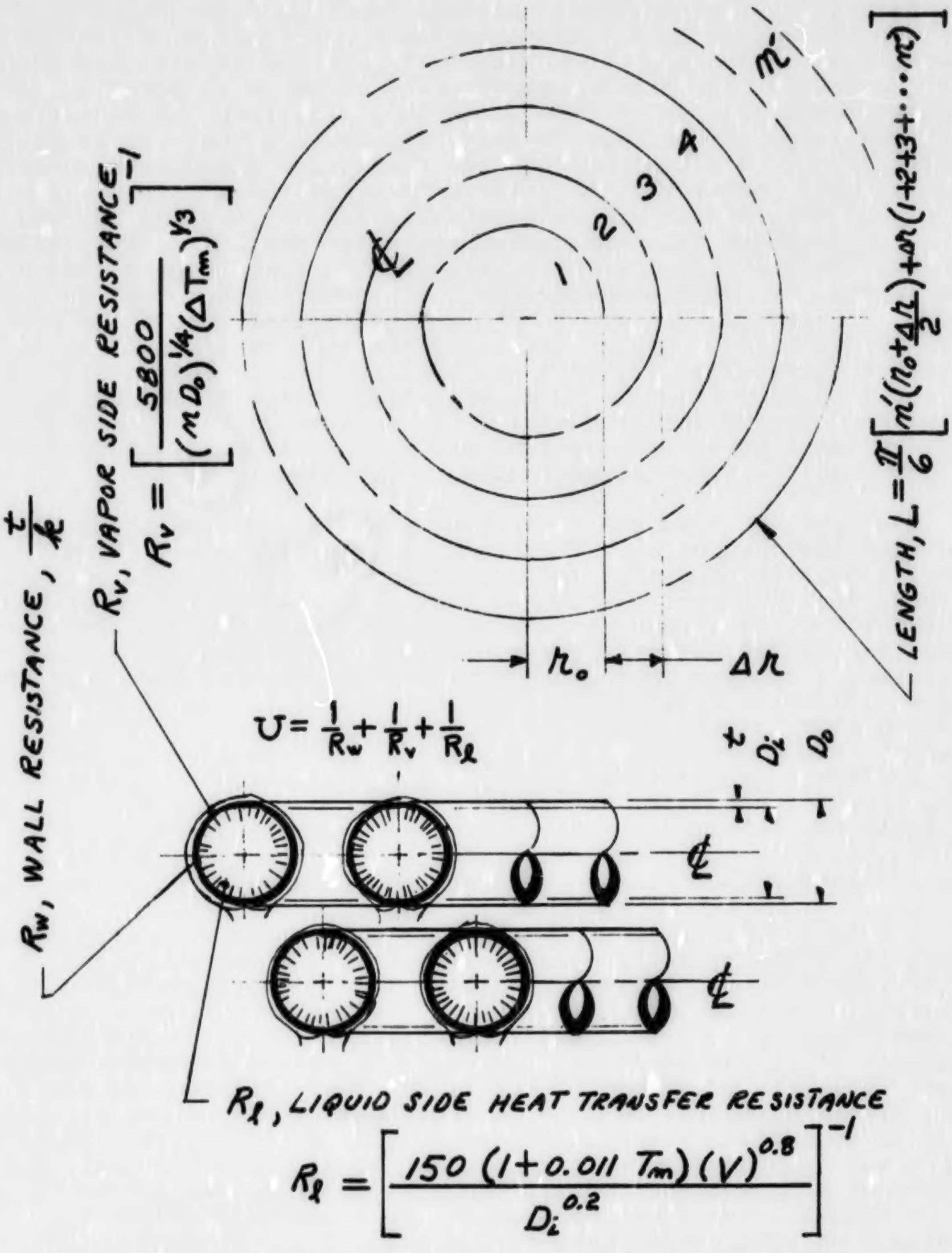
$$h_f' = h_f + x(h_1 - h_f) \tag{10}$$

which shows that the fraction x decreases as temperature $T_1$ increases. Hence the pump capacity requirement, $\dot{\omega}$, increases, and, for a fixed heat exchanger size the power requirement increases.

The heat exchanger size requirement is related to the evaporator temperature, $T_1$, via the heat transfer equation:

$$L = \frac{\dot{\omega}(h_3 - h_4)}{U \pi D_o \theta_{lm}} \tag{11}$$

It is seen that the length, L, is directly related to evaporator temperature, $T_1$, through the log-mean temperature difference, $\theta_{lm}$. Further, the overall heat transfer coefficient, $U$, is influenced by the selection of temperature $T_1$. A model of the heat transfer in condensation is illustrated in Figure 7. An important feature of the heat exchanger design is that the coil operates at a relatively high Reynolds Number, on the order of 200,000. This serves two purposes; first, high liquid-side film coefficients are possible, and second, the probability of fouling is greatly reduced. The numerical analysis shows that the values of the liquid side and vapor side film coefficients are of the same magnitude, on the order of 3000 Btu per hr per square foot per °F. Another interesting feature is that the liquid side film coefficient varies inversely with viscosity to the 0.4 power, which is a relatively weak function. Hence, as the liquor viscosity increases with increase in total solids concentration the heat transfer is not strongly affected. And since the Reynolds Number is high (200,000) a threefold increase in viscosity changes the friction factor by only 18% (Moody Diagram). This means that by proper selection of the operating point on the centrifugal pump curve, the change in pump flow and power due to a relatively large increase in viscosity can be made relatively small. Viscosity measurements have shown that the viscosity change for water at 120°F with 30% solids in solution is on the order of 2:1 compared to tap water at room temperature. Since it takes a viscosity change on the order of 6:1 to noticeably decrease the head and capacity of a centrifugal pump, the performance of the recycle loop can be made to be relatively independent of % solute in the liquor solution.



R_W, WALL RESISTANCE, t/k
R_V, VAPOR SIDE RESISTANCE
R_V = [5800 / ((n D_o)^{1/4} (ΔT_m)^{1/3})]^{-1}
1
2
3
4
n'
℄
r_o
Δr
LENGTH, L = π/6 [n'(r_o + Δr/2) + Δr(1+2+3+···n')]
U = 1/R_w + 1/R_v + 1/R_ℓ
t
D_i
D_o
℄
℄
R_ℓ, LIQUID SIDE HEAT TRANSFER RESISTANCE
R_ℓ = [150 (1 + 0.011 T_m) (V)^{0.8} / D_i^{0.2}]^{-1}

Figure 7 HEAT TRANSFER MODEL OF CONDENSER COIL (source for $R_V$ & $R_l$: McAdams, W. H., Heat Transmission, 3rd ed., McGraw-Hill, New York, 1954.)

Results of the numerical analysis shown in Figure 6 were obtained by evaluating the aforementioned equations at different values of the evaporator temperature, $T_1$, in the temperature range 152°F to 160°F. The minimal power point is shown to occur at an evaporator temperature of 157°F. At this condition the required shaft power for the compressor drive and recycle pump are respectively, 0.71 HP and 0.26 HP, and the compressor speed requirement is 3140 rpm. Therefore, the motor selections for the compressor drive and recycle pump are respectively, 3/4 HP, and 1/3 HP, and for a single phase 3450 rpm compressor motor the belt drive ratio is 1.09. An additional motor is required to transfer the condensate to the hot water storage tank; its power requirement is small. However, condensate pumps are inefficient - so a 1/8 HP motor was selected. Hence, the total shaft HP requirement to operate the processor is, (3/4 + 1/3 + 1/8) HP, or 899 watts. The total shaft power divided by an average motor efficiency is the power draw for the processor. For an average efficiency of 50%, the total power draw is 1798 watts - and for a 115 VAC, single phase service, the current draw is 15.6 amperes.

Having calculated the power requirements, it remains to determine the insulation requirement for the processor. From equation 3 it is seen that the insulation should be sized so that the heat loss does not exceed the heat generated by the compressor motor. Using a compressor motor efficiency of 0.50, the heat generation is 560 watts. Then the insulation thickness, y, can be estimated by considering the radial heat transfer across an insulated cylindrical wall. This is illustrated in Figure 8. It is shown that for the steady state operating condition the insulation thickness need not be greater than 1/4 inch (for an outside surface temperature of 120°F). The insulation size, therefore, is governed by the stand-by conditions. Thus, a two-inch thickness was selected for the prototype units in order to minimize the heat loss between runs, and to minimize the start-up time to reach steady-state operating temperature during a run.

Finally, mention should be made of the operational effect due to elevation of boiling point by the solute concentration in the recycle liquor. A rise in boiling point means a reduced saturation pressure, $P_1$. Therefore, at evaporator temperature, $T_1$, the vapor is in the superheat region on the T-S diagram of Figure 3. Then the isentropic compression raises the vapor temperature, $T_2$, to a higher value, $T_2'$, which for the same recovery rate, $\dot{\omega}$ , increases the rate of superheat to the value $(h_2' - h_3)$; this is illustrated in Figure 9. The effect of this phenomenon was ignored because the unit was to be evaluated using a variety of wastewaters. On the other hand, it can be accounted for as CHEMTRIC has done for treated urine and expended photochemicals on other Government contracts.

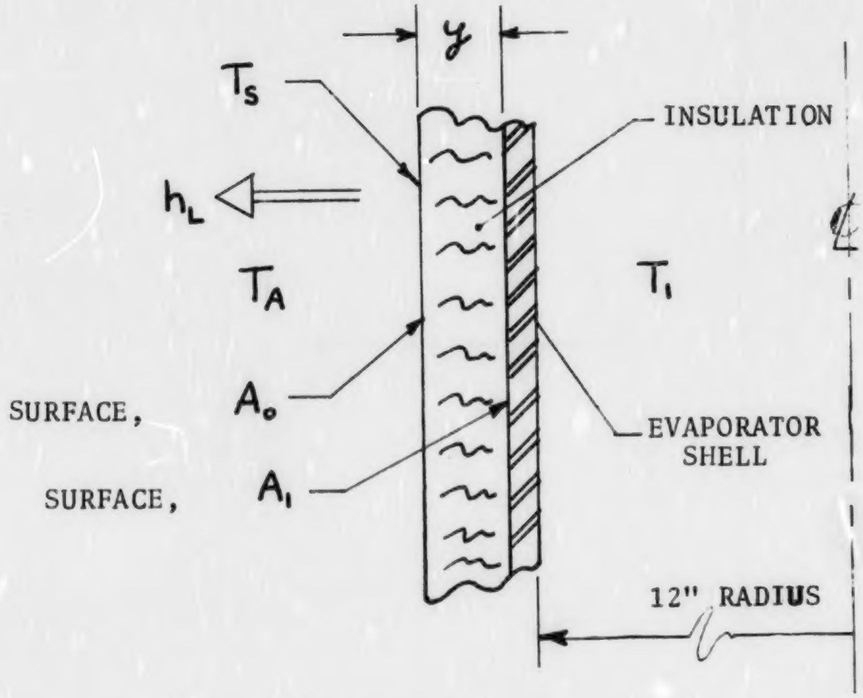

y
$T_s$
INSULATION
$h_L$
$T_A$
$T_1$
SURFACE,
$A_o$
EVAPORATOR SHELL
SURFACE,
$A_1$
12" RADIUS

Figure 8 MODEL OF INSULATION HEAT LOSS

$$\text{Heat loss, } h_L = \frac{T_1 - T_A}{\dfrac{y/k'}{\frac{A_1+A_o}{2}} + \dfrac{1}{(H_c+H_r)A_o}}$$

where values of $(H_c+H_r)$ are given in McAdams, W. H., *Heat Transmission*, 3rd ed, McGraw-Hill, New York, 1954.

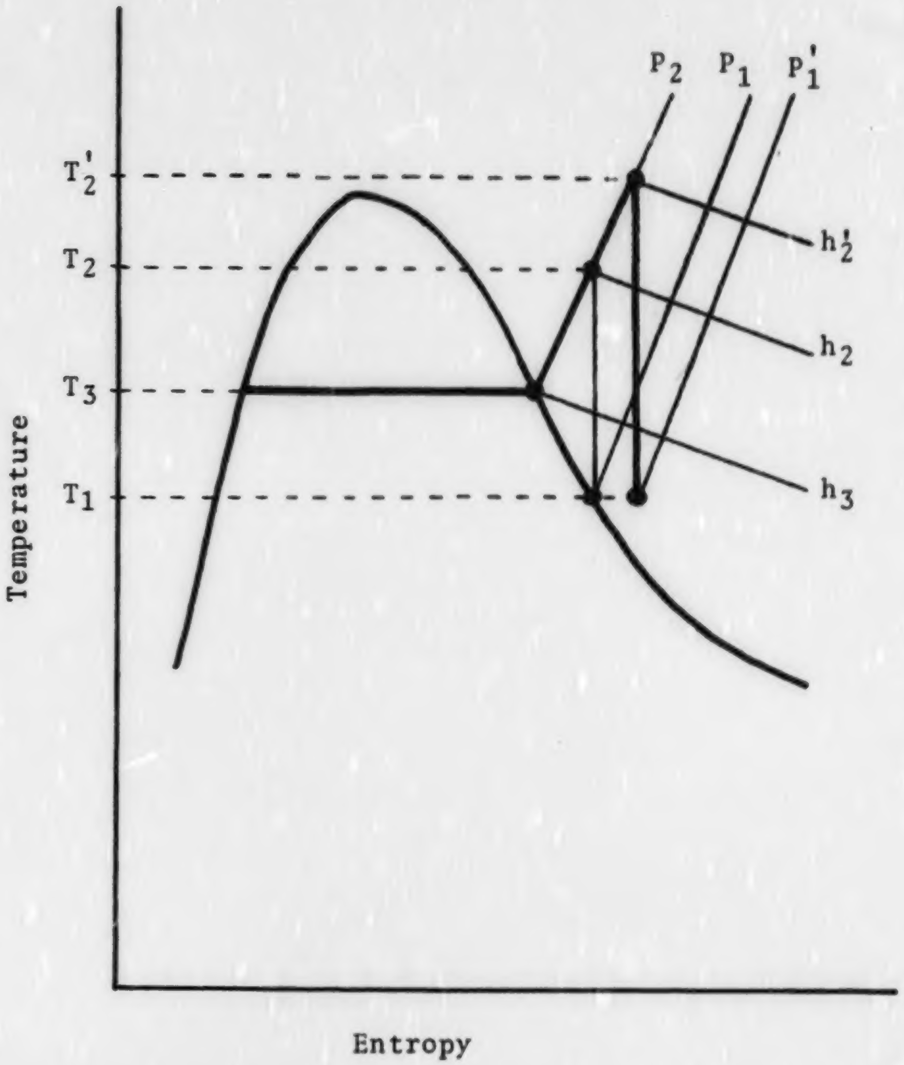

$P_2$
$P_1$
$P_1'$
$T_2'$
$T_2$
$T_3$
$T_1$
$h_2'$
$h_2$
$h_3$
Temperature
Entropy

Figure 9 EFFECT OF BOILING POINT ELEVATION

# SECTION V

# PROTOTYPE DESIGN

Upon completion of the preliminary analysis described in Section IV, mechanical design of prototype hardware was undertaken. This section contains a design description of the prototype assembly. Two identical units were fabricated, of which one unit was used for extended evaluation and development tests. Photographs of the test unit at the test-site in the CHEMTRIC laboratory are shown in Figures 10 and 11.

## Weldment Assembly

The basic elements of the Recycler/Heater system, that is, the processor tanks, holding tank, and storage tank were incorporated into a skeleton weldment assembly as shown in Figure 12. This was accomplished by seal welding three steel sheet sections between the process tank and the storage tank, the left and right tanks respectively in Figure 12. The center section then forms the holding tank. Material of construction for all three tanks was low carbon, commercial-grade, 10-gauge steel sheet. Light-steel channels welded vertically on both sides of the end tanks form the support legs and frame for securing the insulation panels. Additional light channels form a rectangular frame at the bottom to support the recycle and condensate pumps. It is seen in Figures 10, 11, and 12 that all the external control components, wiring and plumbing are accessible when the front insulation panel is removed. In Figure 13, an illustration is given which shows the pertinent volume, area, and linear dimensions in the assembly.

## Processor Tank Assembly

The processor tank contains the evaporator, condenser and compressor drive assembly inside a 10-gauge, 24-inch I.D. by 48-inch long cylindrical shell. The bottom of the shell is closed by a weld-on, standard-type, 24-inch O.D. head. A ring flange is closed by a bolt-on standard head containing a matching ring flange. Removal of the flanged head allows access to the compressor and drive for maintenance. In Figure 14, a top-view photograph reveals the compressor drive assembly, and shows the locations of the inlet and outlet connections to the heat exchanger, pipe line to the spray ring, flexible purge gas line, relief valve, and power connections for the compressor motor. The additional flexible line which runs along the purge gas line was used for thermocouple wires. A thermocouple was located inside

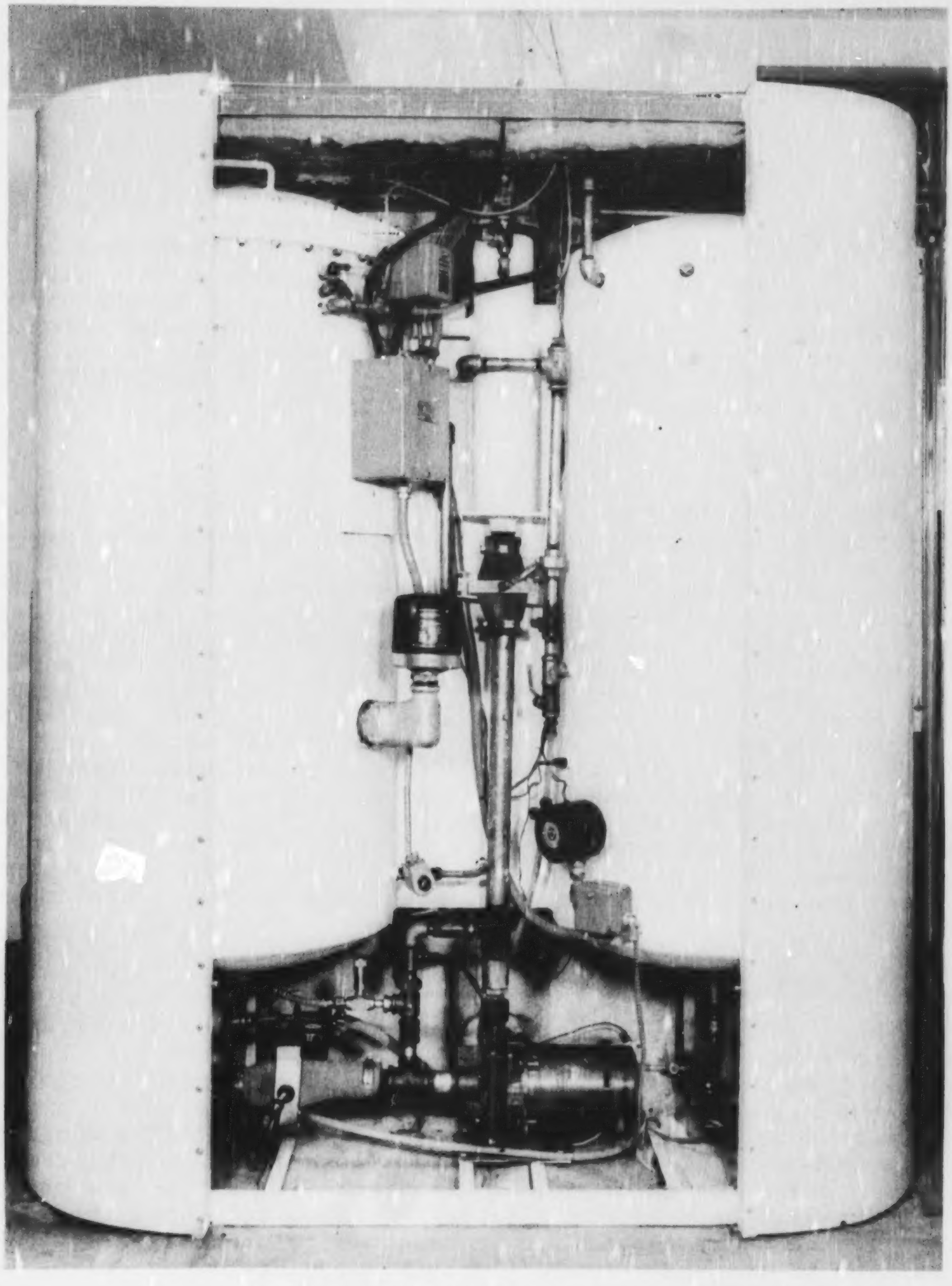


Figure 10 RECYCLER/HEATER WITH DOOR REMOVED

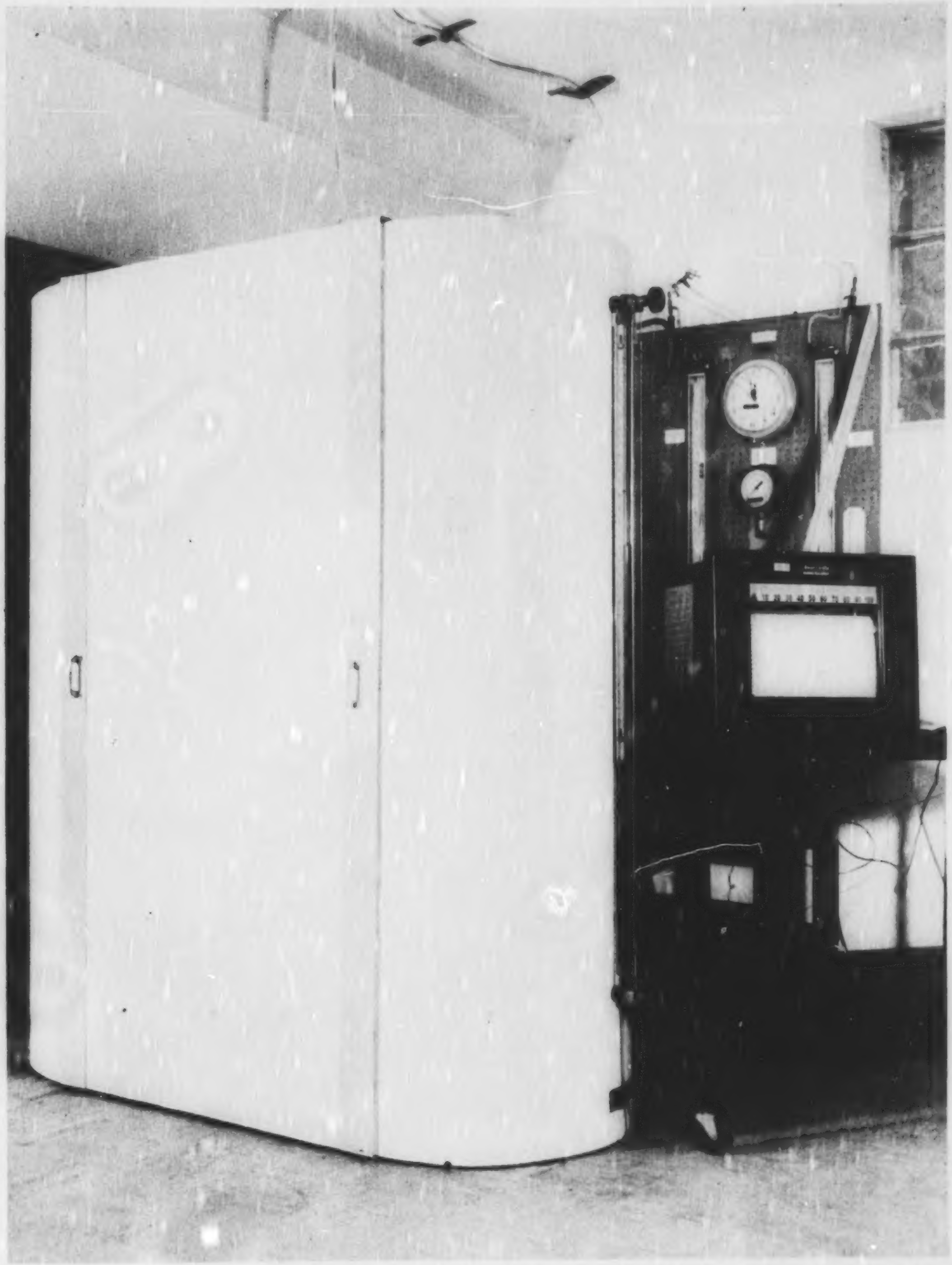


Figure 11 RECYCLER/HEATER WITH TEST EQUIPMENT

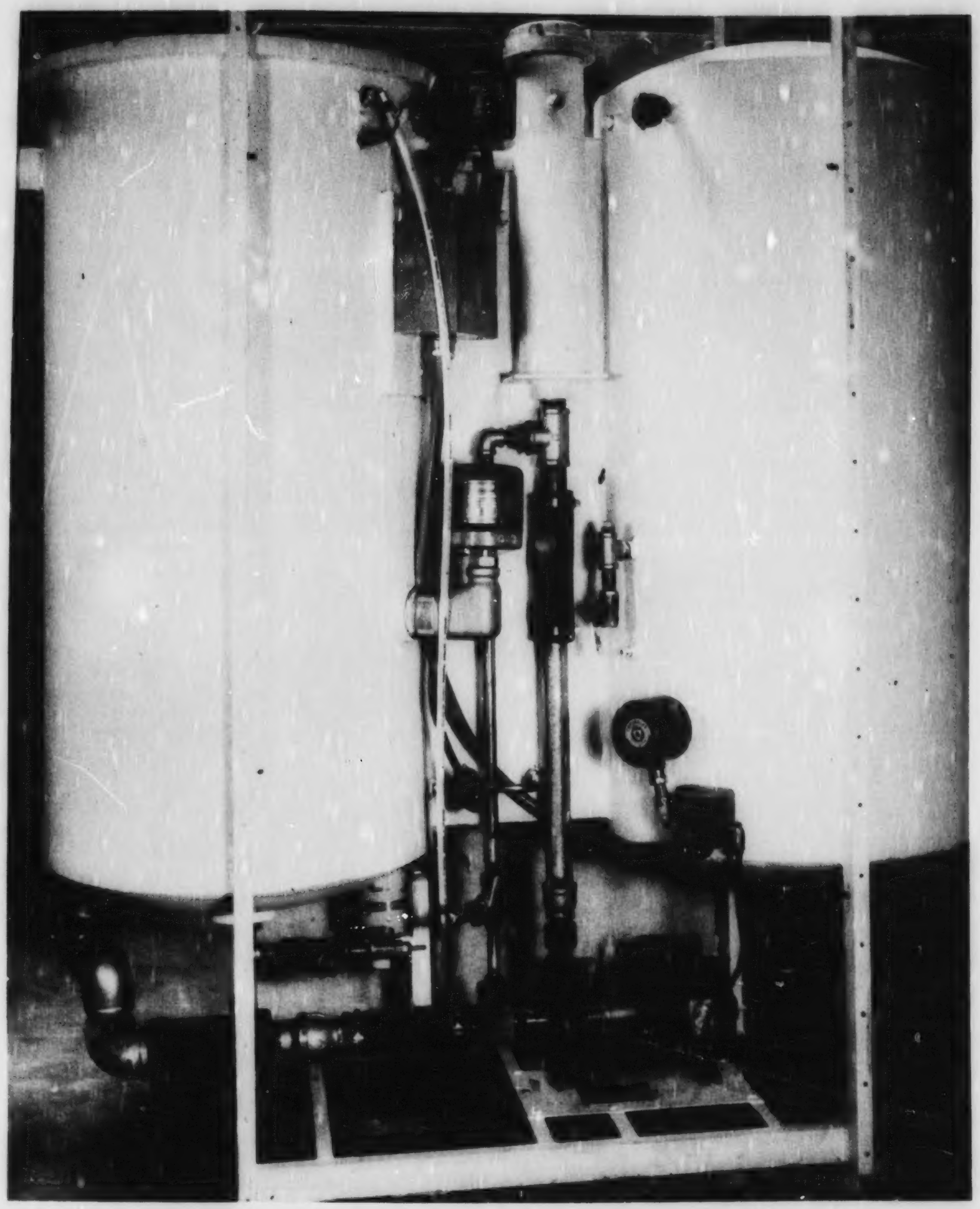
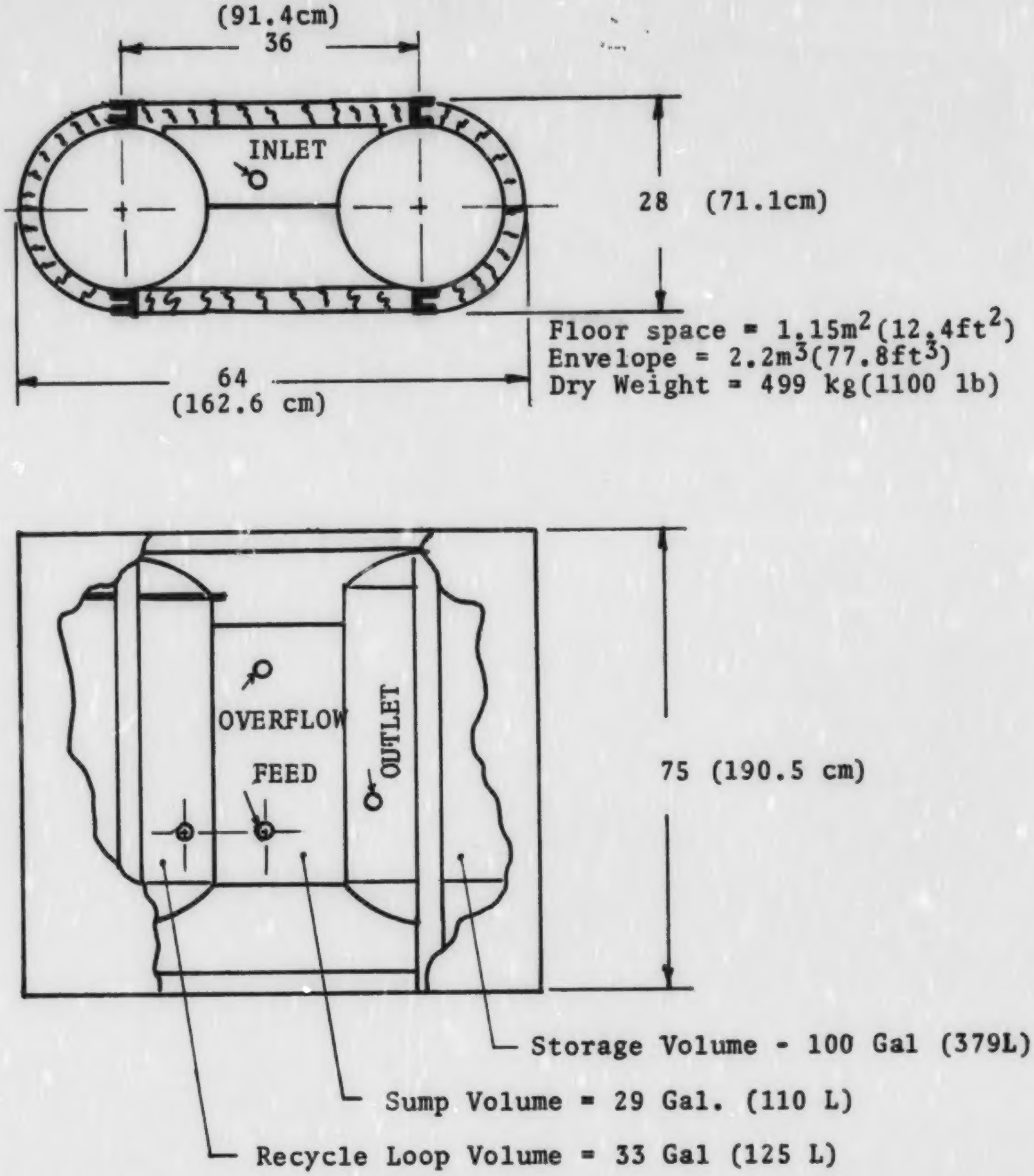


Figure 12  RECYCLER/HEATER WITHOUT INSULATION


(91.4cm)
36
INLET
28 (71.1cm)
64
(162.6 cm)
OVERFLOW
FEED
OUTLET
75 (190.5 cm)

Floor space = 1.15m$^2$(12.4ft$^2$)
Envelope = 2.2m$^3$(77.8ft$^3$)
Dry Weight = 499 kg(1100 lb)

Storage Volume - 100 Gal (379L)
Sump Volume = 29 Gal. (110 L)
Recycle Loop Volume = 33 Gal (125 L)

Figure 13 RECYCLER/HEATER PHYSICAL DIMENSIONS

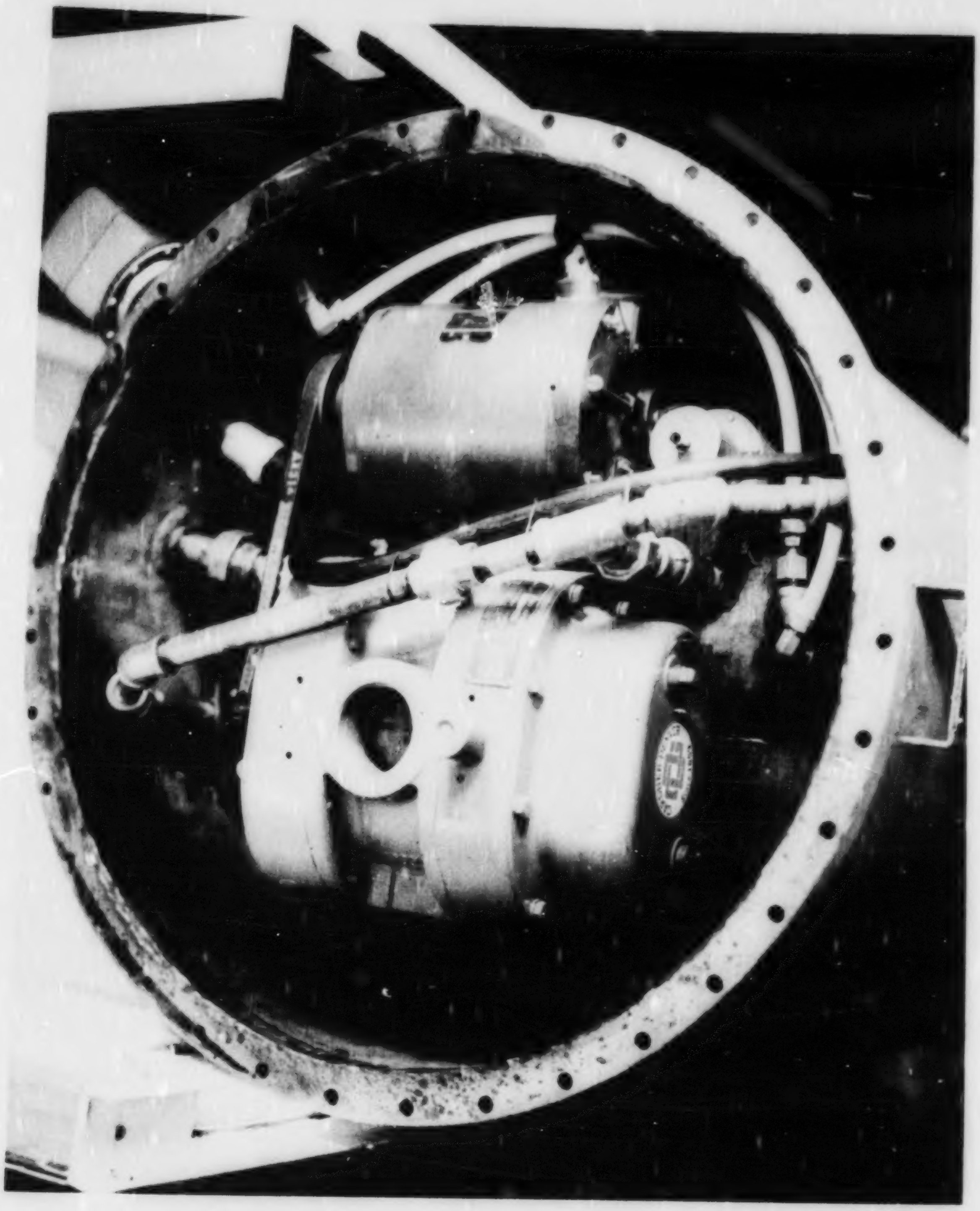


Figure 14  PROCESS TANK WITH HEAD REMOVED

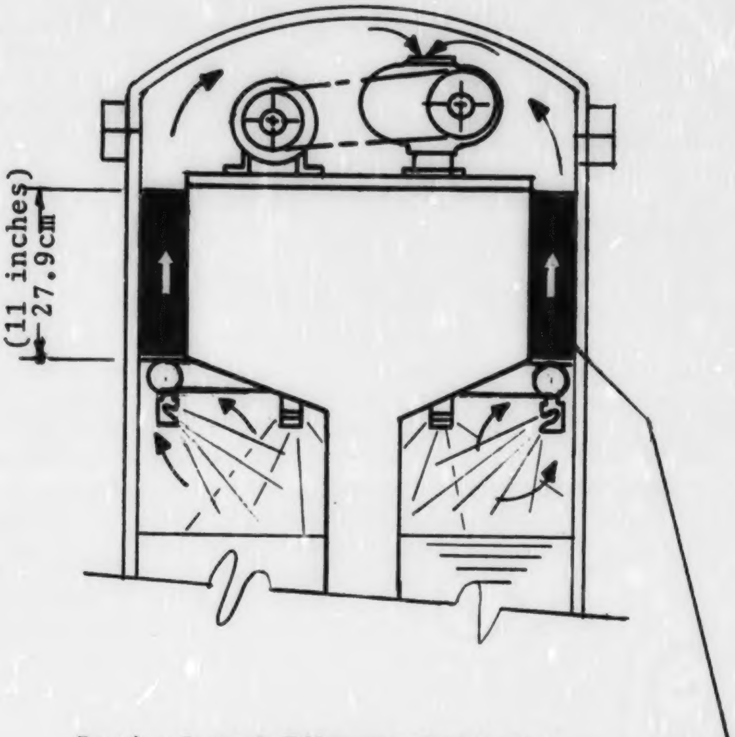
the condenser shell to measure compressor discharge temperature, $T_2$.

During the evaluation test program in order to prevent the carry-over of foam through the compressor it was found convenient to add an entrainment control medium inside the processor tank. This material is packed into the annulus formed by the evaporator shell I.D. and condenser shell O.D. The assembly is shown in Figure 15.

## Components and Controls

Except for the weldment assembly, condenser coil and spray ring assemblies, and compressor relief valve which were designed by CHEMTRIC, all the system components were off-the-shelf type purchased items. These components were selected for industrial grade quality and availability throughout the country. Figure 16 is a schematic arrangement of the system in which all the purchased parts are identified by numbered bubbles. These numbers refer to the component descriptions given in Table 1. In Figure 17 an electrical schematic identifies the control components. In the evaluation test program, described in Section VI, the sump level control and storage tank pressure control were not used; also, an interlock between the compressor motor and storage tank heater was not used. The purging circuit arrangement, and condensate pump operation, as shown in Figure 16 was the result of development efforts during the evaluation test program. Referring to Figures 16 and 17, for home use the system would operate as follows.

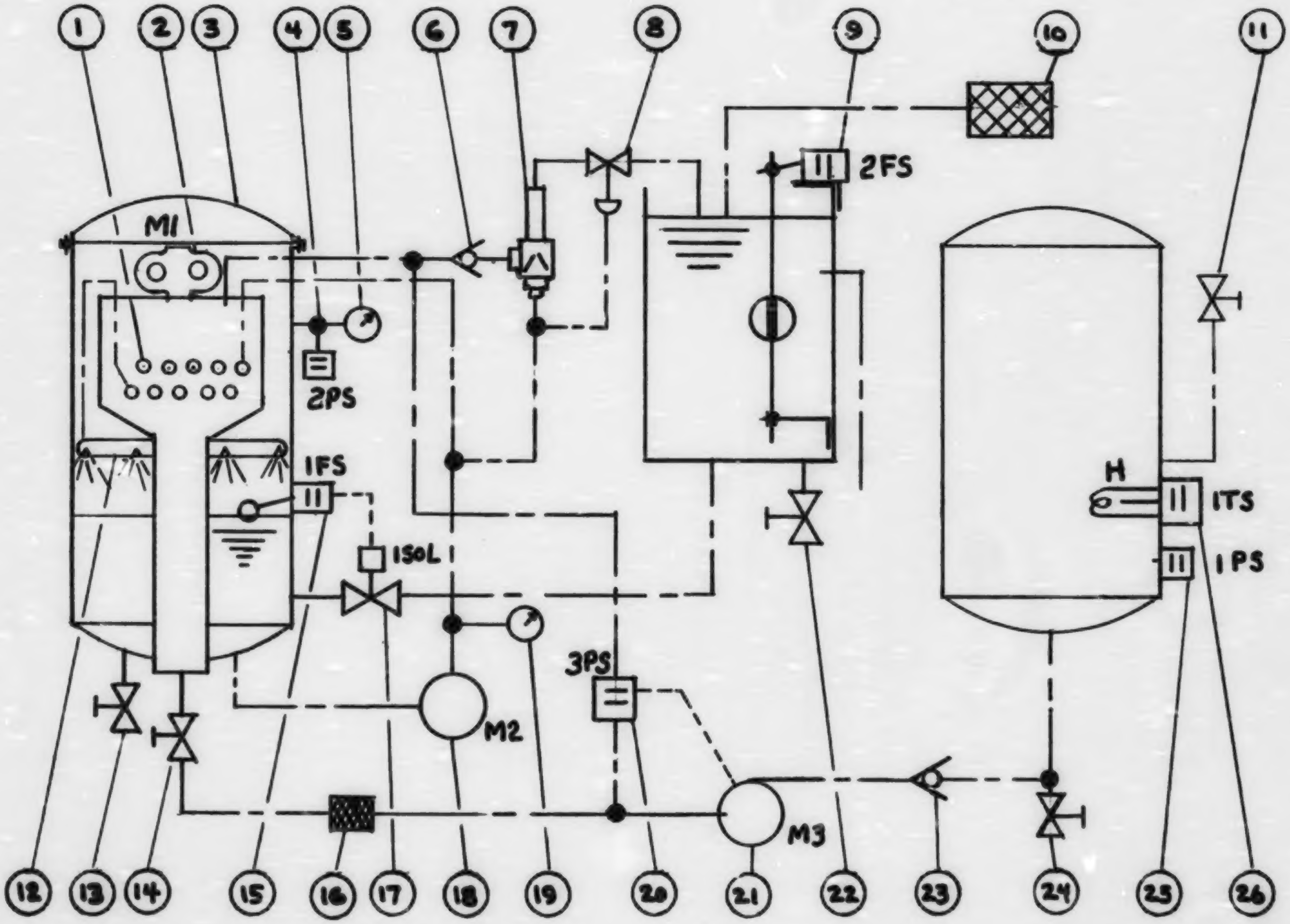
From a wall-mounted circuit breaker, single-phase power (115 VAC, 20A 60 HZ) is brought to a terminal box located on the weldment assembly (upper left center in Figure 11). When the circuit breaker is closed the water heater will be "on" whenever the storage tank temperature is below 160°F, provided the compressor is not "on". The recycle pump will be "on" provided the wastewater level in the sump is above the feed line, and the storage tank pressure is below 42 psig. Operations of the recycle pump provides fluid power for the jet pump which continuously purges the condenser of air and other non-condensible gases. Discharge from the jet pump, 2.5 gpm, is directed into the feed sump, where the gas phase is readily separated from the liquid phase at atmospheric pressure. Whenever the liquid level in the processor tank is reduced by one inch, a solenoid-operated pinch valve is actuated which allows wastewater from the sump to enter the processor. When the jet pump evacuates the processor tank to 21 inches HG vacuum, a vacuum switch is actuated. From a "cold" start, that is, the processor is initially at atmospheric pressure and the wastewater is aerated; approximately 1½ hours is required to reach operating vacuum pressure. Actuation of the vacuum switch turns "on" the compressor. Then the condensate pump is controlled by a differential pressure switch which turns "on" the pump when the product water column in the condenser reaches



Reticulated Fibrous Pellets
( Beco Engineering Company )

Figure 15 SKETCH SHOWING DEMISTER LOCATION

30 inches, and turns "off" the pump when the column is lowered to the suction line of the pump. This insures that the pump suction is always flooded. Whenever the wastewater level in the sump is too low and/or the hot water storage tank is filled (pressure at 60 psig) the recycle pump and power to the compressor and product pump are turned "off". Then a normally closed pinch valve shuts off the flexible discharge line on the jet pump in order to maintain the processor vacuum.


1
2
3
4
5
6
7
8
9
10
11
M1
2PS
1FS
1SOL
2FS
M2
3PS
M3
H
1TS
1PS
12
13
14
15
16
17
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19
20
21
22
23
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25
26

Figure 16 ARRANGEMENT OF COMPONENTS AND CONTROLS

Table 1 COMPONENT IDENTIFICATION

| Item No. | Description | Source |
|---|---|---|
| 1 | Condenser Tube Ass'y | Dormont Mfg. Co. |
| 2 | Rotary Lobe Compressor | Gardner Denver |
| 3 | Weldment Ass'y | CHEMTRIC, Inc. |
| 4 | Vacuum Switch | Square-D-Co. |
| 5 | Vacuum Gauge | U.S. Gauge Co. |
| 6 | Ball Float Check Valve | CHEMTRIC, Inc. |
| 7 | Jet Pump | Penberthy |
| 8 | Reverse Acting, Hydraulic Actuated Pinch Valve | CHEMTRIC, Inc. |
| 9 | Float Control Ass'y | Square-D-Co. |
| 10 | Lint Filter | CHEMTRIC, Inc. |
| 11 | Shut-Off Valve | Apollo Valve Div. |
| 12 | Spray Ring Ass'y | Dormont Mfg. Co. |
| 13 | Shut-Off Valve | Apollo Valve Div. |
| 14 | Shut-Off Valve | Apollo Valve Div. |
| 15 | Liquid Level Control | Magnitrol Div. |
| 16 | "Y" Strainer | Paget |
| 17 | Solenoid Actuated Pinch Valve | Trombetta Corp. |
| 18 | Centrifugal Pump | Worthington Inc. |
| 19 | Pressure Gauge | U.S. Gauge Co. |
| 20 | Differential Pressure Switch | Square-D-Co. |
| 21 | Rotary Vane Pump | Procon Inc. |
| 22 | Shut-Off Valve | Apollo Valve Co. |
| 23 | Check Valve | Bivco Valve Corp. |
| 24 | Shut-Off Valve | Apollo Valve Co. |
| 25 | Pressure Switch | Square-D-Co. |
| 26 | Heater Control | Chromalox |

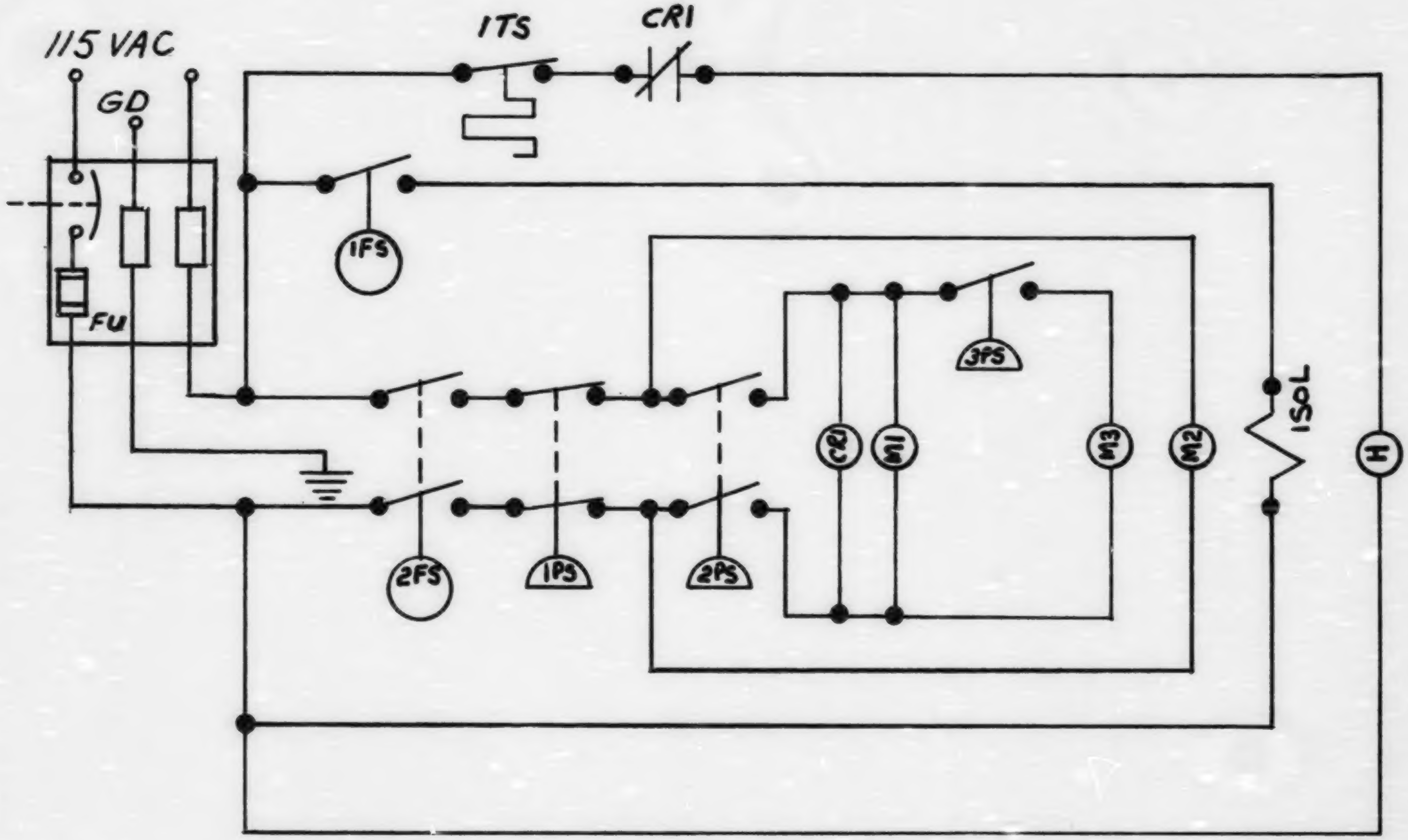
115 VAC
GD
FU
1TS
CR1
1FS
2FS
1PS
2PS
3PS
CR1
M1
M3
M2
1SOL
H

Figure 17 RECYCLER/HEATER ELECTRICAL SCHEMATIC

# SECTION VI

# EVALUATION TESTS

Development tests and extended water quality evaluation tests were conducted on the prototype water Recycler/Heater unit shown in Figures 10 and 11. The primary objectives of these tests were (1) an evaluation of the overall mechanical, hydrodynamic and thermodynamic performance of the system, (2) a determination of the physical, chemical and biological characteristics of the recovered water, and (3) an evaluation of the dependence of water quality on liquor concentration. The tests were conducted in two phases with two very different waste streams. The first phase was a 38-day test series using real laundry water. The second phase was a 21-day test series using a synthetic wastewater stream which simulates concentrated hospital wastewater. This section presents a detailed description of the apparatus and test procedures used, and the results of water quality analyses and system performance measurements.

## Real Laundry Water

For these tests real laundry water was obtained by washing, in a semi-automatic Kenmore washing machine, soiled clothes supplied by CHEMTRIC employees. Seven employees participated in the tests. The clothes could generally be classified as "old clothes" such as work shirts and pants, children's play clothes, laboratory coats, throw rugs, cleaning rags, furniture covers, and drop clothes. A good supply of children's clothes and underclothing were included since the homes of all the participants contained young children. No attempt was made to quantify the washing operation. However no complaints of a "poor" wash were voiced by any of the participants' families. The wash load during the tests varied from 4.0 lb to 12.60 lb with an average value of 7.15 lb (3.2 kg). A 30 gallon (114 liters) volume of water and 2.8 oz (80 grams) of FSN-7930-00-634-3935 Type 1 cleansing agent were used for each load of soiled clothing. Washing consisted of a single wash and rinse cycle, each lasting from 1/2 to 1 hour, and each using 15 gallons (571) of recovered water. The laundry soap was selected since laboratory tests at CHEMTRIC indicated that it had a lower sudsing level than the popular household detergents.

### Test Apparatus

A schematic of the test set-up is given in Figure 18. The

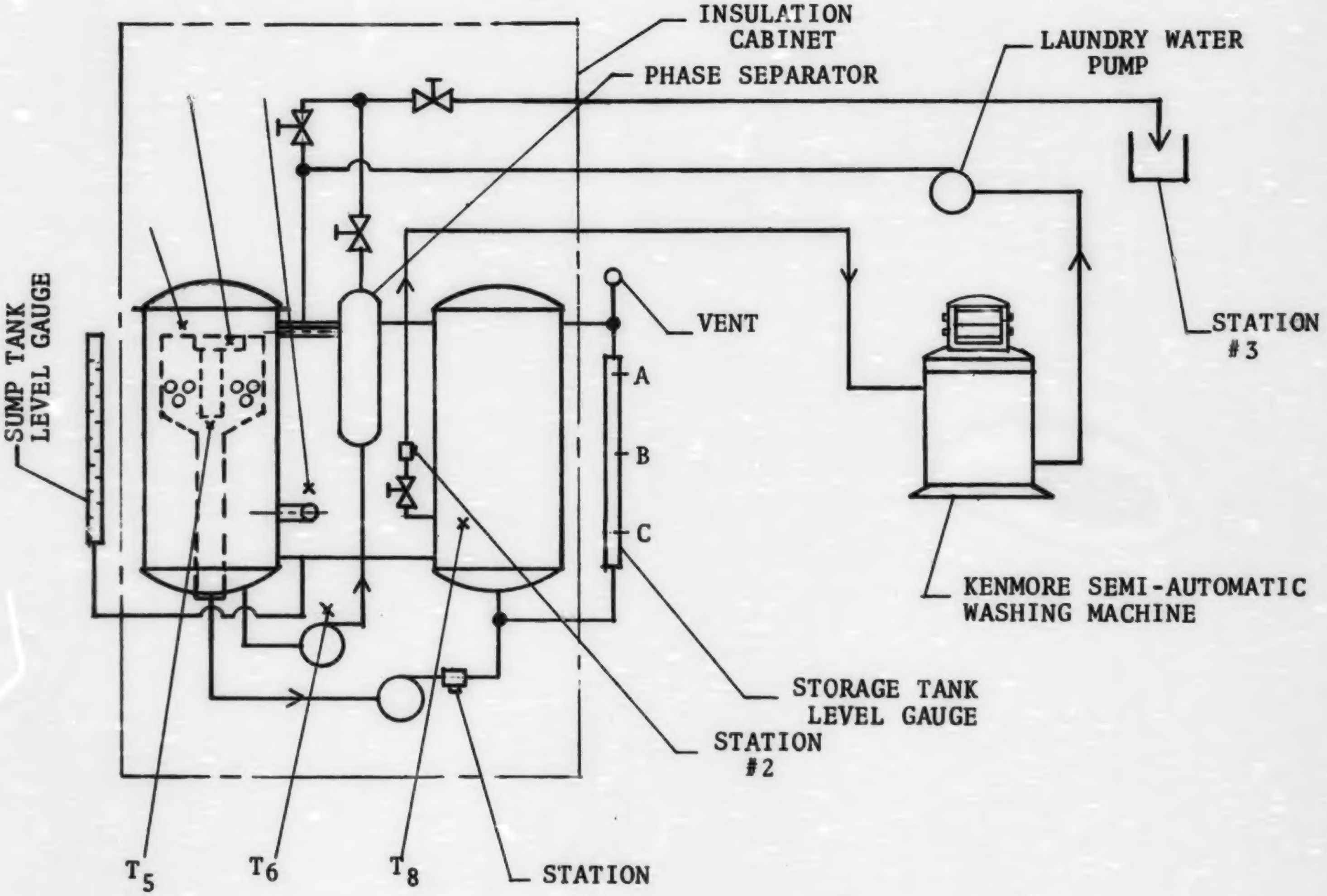
INSULATION CABINET
LAUNDRY WATER PUMP
PHASE SEPARATOR
VENT
STATION #3
SUMP TANK LEVEL GAUGE
A
B
C
KENMORE SEMI-AUTOMATIC WASHING MACHINE
STORAGE TANK LEVEL GAUGE
STATION #2
$T_5$
$T_6$
$T_8$
STATION

Figure 18 REAL LAUNDRY WATER TEST ARRANGEMENT

external recycle loop consists of the Recycler, the washing machine, and a laundry water pump. Each test day consisted of a single test run in which a single load of clothes was washed using stored product water from the Recycler; then the waste laundry water was returned to the Recycler for reprocessing. Processing data were recorded at regular time intervals during each run, and all the data referenced to hours into the run. Regarding the washing operation, the load weight, amount of soap and anti-foam additives, and the amount of make-up water (tap water) were recorded. At the locations indicated in Figure 18, the variable temperature field was recorded with a Honeywell Electronik 15-point strip-chart recorder which measured the emf generation from type T thermocouples. The evaporator and condenser saturation temperatures were obtained by measurements of the saturation pressures $P_1$ and $P_2$, relative to the local atmosphere, using Meriam mercury manometers. These pressure measurements also provided the $\Delta P$ across the compressor and the compressor compression ratio. Total power input to the processor was measured with a Simpson panel wattmeter; power and pressure measurements, recovery rate, recycle pump pressure, and the ambient temperature and local barometer were also recorded. Pump pressure was measured with a Helicoid, 0-30 psig, test gauge, and recovery rate was determined with the use of a calibrated sight glass tube mounted to the storage water tank; changes in water level per 1/2 hour interval were recorded.

Referring again to Figure 18, at stations 1, 2, and 3 water samples were taken of the raw condensate, stored condensate (product water), and concentrate (recycle liquor), respectively. The condensate samples were taken through 5/8-inch diameter rubber septums (Hamilton). Via these samples the physical, chemical and biological characteristics of the product water were monitored during each test run. Resistivity was measured with a YSI Model 31 Conductivity Bridge; turbidity was measured with a Hach Laboratory Turbidimeter, Model 2100A; the pH of the product water was measured with a Corning pH meter, Model 7. The daily build-up in concentration of dissolved solids was measured using equipment and procedures specified in Standard Methods for Examination of Water and Waste Water, Am. Pub. Health Assoc., 13th edition. A Voland Model 220-D analytical balance was used for weight measurements. Biological conditions were assessed by positive-negative tests for sterility. Using sterile sampling apparatus, one ml of sample water was added to each of three tubes of Fluid Thioglycollate Medium (Scientific Products Cat. No. 21195), and the resulting broth incubated at least 48 hours. Chemical conditions were assessed daily via COD determinations. The equipment and procedures were those specified in "Standard Methods". Near the end of the test series a detailed chemical analysis of product water samples was conducted by the Nalco Chemical Company, Analytical Services Division. These tests were conducted for organics, metals, and ions.

## Test Procedure

In the first day's test 114 liters of tap water from the storage tank was pumped directly into the sump for processing in order to establish a baseline; the recycling of waste laundry water commenced the second test day. Referring to the test schematic in Figure 18, the day-to-day test procedure was as follows. At the beginning of each test day at 0800 hours product water from the storage tank was gravity fed into the washing machine to begin the wash cycle. The quantity used was determined by draining the tank to a level marked position "B" on the liquid level sight gauge. Make-up water (tap water) was then added directly to the machine; the amount of make-up was determined by the difference between the water level at the end of the previous test run and a level marked position "A" on the gauge. The volumetric difference between levels "A" and "B" was 57 liters.

Upon completion of the wash cycle the waste laundry water was pumped into the feed sump of the Recycler, and the processor turned "on" - that is, the recycle pump, compressor, and condensate pump were started via a panel switch. This occurred at 0900 hours and marked the beginning of the test run, and a water sample was taken from the storage tank at station #1. From this point of time into the run, operational conditions, pressures, temperatures, power and recovery rate were monitored at 1/2 hour intervals. After the processor had been running for 1/2 hour to 2 hours an additional 57 liters of product water from the storage tank was fed into the washing machine for the rinse cycle. Upon completion of the rinse cycle the clothes were passed through the machine's wringer rolls, then manually wrung to minimize the make-up water requirement. The waste rinse water was then pumped into the feed sump.

After 4 hours into the run at 1300 hours a water sample of the raw condensate was taken at station #1. Near the end of the run, typically at 1430 hours a sample of concentrate was taken at station #3. Termination of the run was determined, and the processor turned off via the panel switch, when the sump level was lowered to a marked position on a sight gauge (slightly above the feed line). When this occurred the calibrated level gauge on the storage tank indicated the total wastewater processed during the run. The difference between this quantity and 114 liters was the make-up water requirement for the next test run. When the processor was turned off, the thermostatically controlled heater in the storage tank remained "on" in order to maintain temperature between runs. Typically, cooling of the processor tank occurs between runs. This cooling caused a drop in the absolute pressure so that the next run always began with the processor at a higher vacuum level corresponding to the saturation pressure at the lower temperature.

## Test Results

Quantitative information was obtained throughout this test series to establish both quality of the product water and mechanical performance of the system. The analytical results on water quality are presented in Tables 2 and 3. Table 2 represents the results of daily in-house analyses performed by CHEMTRIC, while Table 3 contains the results of detailed analyses for trace metals and other chemical substances performed by Nalco Chemical Company on water samples taken near the end of the test series (test run #32).

The data presented in Table 2 are grouped according to consecutive days on which testing was performed. The blank lines indicate days on which testing was not performed - because test personnel were not available, or time was required to change the testing arrangement.

After the fifth test day into the series foam formation became a problem as evidenced by the sharp increase in turbidity of the raw condensate. As the stored condensate was mixed with raw condensate its turbidity began to rise; this trend continued for the next eight test days through the thirteenth test run. At the end of this run an antifoam agent (Union Carbide SAG 470 Silicone Antifoam) was mixed into the recycle liquor at a concentration of 0.16%. Then, subsequent test runs included antifoam additions to the wash cycle at the amounts indicated in Table 2. These amounts represent concentration per 30 gallons (114 liters) which are very low for the 16 grams dosage to medium for the 160 grams dosage - according to the manufacturer's suggested starting concentration.

The final five test runs were conducted without the use of any antifoam additive; instead, an entrainment control medium or demister was installed within the processor tank as shown in Figure 15. The data indicates that water quality remained stable. It is noteworthy that the physical characteristics of the stored condensate or product water at the end of the test series are nearly identical to the original tap water in the storage tank on the first test run. The COD, however, increased from a value below 10 mg/l to 60 ml/l on the last test day. As evidenced by continuing negative results from the sterility tests, the product water remained sterile throughout the test series.

Physical characteristics and the COD of the concentrate and feed stock were determined during test runs 27 and 28 respectively; these are presented in Table 4. Referring to the feed stock, a 1:1 mixture of used wash and used rinse water, the COD of the product water represents a 90% reduction - that is, from 600 ppm to 60 ppm. Referring to the concentrate, the reduction is 99.6%. Both the feed and concentrate are alkaline, having a pH of 9+.

Table 2 LAUNDRY TEST DAILY ANALYSES

| Test No.& Code* | Wash Load (kg) | Make -Up (1) | Anti Foam (g) | Total S (g/1) | | Sterile (+/-) | | pH (units) | | Turbidity (Jtu) | | Sp. Res. (kohm-cm) | | COD (mg/1) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | S-2+ | S-3 | S-1 | S-2 | S-1 | S-2 | S-1 | S-2 | S-1 | S-2 | S-1 | S-2 |
| 01--# | 0.0 | 0 | 0 | .073 | 0.5 | --- | --- | NST | 7.1 | 2 | 10 | NST | 9 | NST | 10 |
| 02-A | 3.8 | 4 | 0 | .023 | 1.4 | --- | --- | 7.5 | 7.3 | 3 | 10 | 45 | 12 | NST | 10 |
| 03-V | 2.5 | 5 | 0 | .027 | 1.8 | --- | --- | 7.6 | 7.3 | 4 | 9 | 81 | 16 | NST | 20 |
| 04-B | 4.0 | 9 | 0 | .057 | 2.1 | --- | --- | 8.0 | 7.5 | 5 | 6 | 76 | 18 | NST | 10 |
| 05-A | 3.3 | 10 | 0 | .025 | 2.9 | --- | --- | 7.9 | 7.5 | 3 | 7 | 45 | 19 | NST | 34 |
| 06-V | 2.9 | 24 | 0 | .018 | 3.3 | --- | --- | 7.5 | 7.4 | 40 | 9 | 18 | 19 | NST | 14 |
| 07-W | 5.2 | 0 | 0 | .030 | 4.4 | NST= | --- | NST | 7.4 | NST | 20 | NST | 17 | NST | 30 |
| 08-A | 5.7 | 0• | 0 | .181 | 4.3 | --- | --- | 7.7 | 8.5 | 110 | 72 | 7 | 9 | NST | 75 |
| 09-V | 3.0 | 13 | 0 | .143 | 6.0 | --- | --- | 7.2 | 8.0 | 160 | 70 | 6 | 9 | NST | 95 |
| 10-B | 3.2 | 10 | 0 | .308 | 4.9 | --- | --- | 6.8 | 8.2 | 21 | 125 | 15 | 6 | NST | 45 |
| 11-P | 3.2 | 18 | 0 | .216 | 5.1 | --- | --- | 8.6 | 8.1 | 170 | 120 | 5 | 7 | NST | 175 |
| 12-A | 3.2 | 10 | 0 | .310 | 7.3 | --- | --- | 8.0 | 8.2 | 170 | 130 | 4 | 5 | NST | 195 |
| 13-W | 4.5 | 10 | 208 | .371 | 7.6 | +-- | --- | 7.9 | 8.3 | 230 | 150 | 3 | 5 | NST | 315 |
| 14-B | 3.4 | 10 | 16 | .571 | 8.6 | --- | --- | 7.1 | 8.3 | 7 | 230 | 16 | 4 | NST | 800 |
| 15-V | 2.9 | 10 | 16 | .398 | NST | NST | --- | NST | 8.3 | 100 | 155 | NST | 5 | NST | 440 |
| 16-P | 3.3 | 0 | 80 | .601 | 10.1 | --- | --- | 7.1 | 8.4 | 6 | 245 | 10 | 4 | NST | 964 |
| 17-W | 3.1 | 10 | 80 | .307 | 10.8 | --- | --- | 6.7 | 8.0 | 4 | 130 | 18 | 5 | NST | 275 |
| 18-B | 3.4 | 3 | 80 | .196 | 11.6 | --- | --- | 6.9 | 8.0 | 4 | 86 | 16 | 7 | NST | 308 |
| 19-A | 3.6 | 3 | 80 | .101 | 12.5 | --- | --- | 6.9 | 8.2 | 5 | 55 | 20 | 8 | NST | 175 |
| 20-V | 4.0 | 7 | 80 | .107 | 13.4 | --- | --- | 6.9 | 7.6 | 4 | 35 | 15 | 10 | NST | 115 |
| 21-V | 2.7 | 3 | 80 | .035 | 13.5 | --- | --- | 7.2 | 7.9 | 5 | 30 | 14 | 10 | NST | 60 |

See Notes On Next Page

Table 2 Continued.

| Test No.& Code | Wash Load (kg) | Make -Up (1) | Anti Foam (g) | Total S (g/1) |  | Sterile (+/-) |  | pH (units) |  | Turbidity (Jtu) |  | Sp. Res. (kohm-cm) |  | COD (mg/1) |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | S-2 | S-3 | S-1 | S-2 | S-1 | S-2 | S-1 | S-2 | S-1 | S-2 | S-1 | S-2 |
| 22-A | 2.8 | 6 | 80 | .056 | 14.2 | --- | --- | 6.9 | 7.8 | 5 | 21 | 13 | 10 | NST | 95 |
| 23-B | 3.1 | 8 | 80 | .022 | 14.6 | --- | --- | 6.7 | 7.8 | 6 | 15 | 16 | 10 | NST | 85 |
| 24-W | 2.3 | 5 | 80 | .030 | 15.5 | --- | --- | 7.1 | 7.6 | 6 | 13 | 13 | 10 | NST | 70 |
| 25-V | 3.6 | 10 | 80 | .032 | 14.9 | --- | --- | 7.1 | 7.9 | 6 | 10 | 13 | 10 | NST | 60 |
| 26-A | 2.7 | 8 | 240 | .016 | 15.1 | --- | --- | 7.4 | 7.9 | 8 | 8 | 13 | 11 | NST | 55 |
| 27-A | 2.8 | 10 | 160 | .409 | 17.9 | --- | --- | 7.2 | 8.2 | 8 | 160 | 16 | 4 | NST | 966 |
| 28-B | 2.9 | 12 | 160 | .274 | 18.6 | --- | --- | 7.5 | 8.3 | 7 | 100 | 15 | 6 | NST | 250 |
| 29-W- | 2.7 | 5 | 160 | .122 | 17.7 | --- | --- | 8.1 | 8.0 | 1 | 66 | 17 | 8 | NST | 155 |
| 30-B | 2.6 | 3 | 160 | NST | 18.6 | NST | NST | 7.0 | NST | 7 | NST | 11 | 10 | NST | NST |
| 31-A | 3.1 | 4 | 160 | NST | 21.5 | --- | --- | 7.3 | 8.0 | 7 | 27 | 20 | 10 | NST | NST |
| 32-V | 2.4 | 5 | 160 | NST | 17.8 | --- | --- | 6.9 | 7.7 | 2 | 20 | 10 | 10 | 55 | NST |
| 33-J | 5.2 | 10 | 160 | NST | 20.9 | --- | --- | 6.8 | 7.1 | 6 | 21 | 11 | 10 | 40 | NST |
| 34-A | 1.8 | 0 | 0 | .023 | 23.5 | --- | --- | 7.3 | 7.4 | 6 | 32 | 14 | 10 | 60 | NST |
| 35-K | 3.6 | 12 | 0 | NST | 23.9 | --- | --- | 6.8 | 7.5 | 6 | 21 | 11 | 10 | 65 | NST |
| 36-V | 2.3 | 3 | 0 | .017 | 24.5 | --- | --- | 7.1 | 7.5 | 7 | 17 | 10 | 10 | 70 | NST |
| 37-B | 2.3 | 10 | 0 | .020 | NST | --- | --- | 6.6 | 7.2 | 6 | 14 | 14 | 9 | 60 | NST |
| 38-R | 3.4 | 0 | 0 | NST | 25.3 | --- | --- | 6.9 | 7.2 | 6 | 10 | 8 | 8 | 60 | NST |

* Code refers to family whose clothes were washed during test

+ S-1, S-2 & S-3 refer to sample points (see figure 18).

# Test No. 01 was conducted with tap water.

= NST refers to No Sample Taken.

- Sample S-1 on Tests No. 29 & 32 was drawn through a 25 μ filter.

## Table 3 LAUNDRY TEST NO. 32 DETAILED ANALYSES

| Item | Measured* | | Limit+ | |
|---|---|---|---|---|
| Metals: | | | | |
| Barium(Ba), Soluble & Insoluble | 0.5 | mg/1 | 1.0 | mg/1 |
| Cadmium(Cd), " " " | 0.01 | " | 0.01 | " |
| Chromium(Cr), Hexavalent | 0.1 | " | 0.05 | " |
| Copper(Cu), Soluble & Insoluble | 0.04 | " | 1.0 | " |
| Iron(Fe), " " " | 0.1 | " | 0.3 | " |
| Lead(Pb), " " " | 0.1 | " | 0.05 | " |
| Magnesium(Mg), Soluble & Insoluble | 0.02 | " | NS= | |
| Manganese(Mn), " " " | 0.05 | " | 0.05 | " |
| Silver(Ag), " " " | 0.04 | " | 0.05 | " |
| Other Parameters: | | | | |
| Ammonia(N) | 16.0 | mg/1 | NS | |
| Arsenic(As), Soluble & Insoluble | 0.001 | " | 0.05 | mg/1 |
| Chloride(Cl) | 2.0 | " | 250. | " |
| Cyanide(CN), Free & Combined | 0.01 | " | 0.2 | " |
| Fluoride(F), " " " | 0.05 | " | 0.8 | " |
| Methylene Blue Active Substances | 0.12 | " | 0.5 | " |
| Nitrate(N) | 0.2 | " | 45. | " |
| Phenols(Phenol-C6H5OH) | 0.42 | " | 0.001 | " |
| Selenium(Se), Soluble & Insoluble | 0.002 | " | 0.01 | " |
| Sulfate(S) | 2. | " | 250. | " |
| Total Organic Carbon | 20. | " | NS | " |

* Measured by Nalco Chemical Company.
+ U.S. Public Health Service Drinking Water Standards, 1962.
= Not Specified.

Results of the Nalco chemical analysis for metals, ions, and organics, and the physical properties determined by CHEMTRIC on water samples from test run #34 are presented in Table 3. These data represent the quality of the product water with the processor operating at a 2% solids concentration, and a water recovery of 96.3%.

At the end of the test series on the 38th test day the % solids had increased to only 2½% ($2.53 \times 10^4$ mg/l), and the final water recovery was 96.8%. Substantially higher concentrations could have been achieved if more funds were available for testing.

Regarding the mechanical performance of the Recycler system during this test program, Tables 5, 6, and 7 present the variations in system temperatures, pressures, power, and recovery rate. These parameters are presented as time dependent variables in test runs 2, 20, and 38 respectively - that is, for runs at the beginning, middle, and end of the test series. The temperatures and pressures were recorded at the positions indicated in the schematic of Figure 18.

States $T_1$ & $P_1$ and $T_3$ & $P_2$ are the saturation conditions in the evaporator and condenser, respectively; it is assumed that the non-condensible gases exert a negligible partial pressure. Temperature $T_2$ is the compressor discharge temperature; temperature $T_5$ is a measure of superheated vapor temperature at the entrance into the condenser shell, just downstream of the transfer pipe exit. Temperature $T_4$ is a measure of the ambient temperature of the compressor drive motor in the vicinity of the drive pulley approximately 1-inch from the belt surface. Temperature $T_7$ indicates the wastewater temperature in the feed sump as it enters the processor. Temperature $T_6$ is the environment temperature within the insulated enclosure in the vicinity of the recycle pump motor - and temperature $T_8$ is the storage tank temperature which is thermostatically controlled. Hence, for a thermostatically controlled temperature $T_8$, temperatures $T_1$ through $T_7$ gradually increase with time during the run.

Table 7 shows that on the last test day, with the Recycler operating at a solids concentration of 2.5%, 110 liters of water was recovered during a run time of 5 hours, 25 minutes. This sets the average recovery rate at 20.3 liters/hour (5.4 gal/hr). During the process the average power draw was 1773 watts, which sets the total energy consumption at 9.6 kw-hrs. Therefore the specific energy consumption was 87 watt-hours per liter (330 watt-hours per gal). It is seen that the specific energy was lower and recovery rate higher at the end of the test series than at the start of the series. This can be explained by the operational variations between the test runs. These variations were the different set points used to control the storage tank temperature $T_8$ and variations in purging technique. At the start, run #2, the storage tank temperature was set at 170°F. During the course of the tests, the set point was reduced to 160°F, and finally to

## Table 4 LAUNDRY TEST FEED AND CONCENTRATE

### FEED - TEST NO. 28

| Item | Value |
|---|---|
| Total Solids | 1.39 g/liter |
| Specific Resistance | 3,700 ohms-cm |
| pH | 9.1 |
| Turbidity | 320 Jtu |
| Chemical Oxygen Demand | 600 mg/liter |

### CONCENTRATE - TEST NO. 27

| Item | Value |
|---|---|
| Total Solids | 16.0 g/liter |
| Specific Resistance | 310 ohms-cm |
| pH | 9.4 |
| Turbidity | 5,400 Jtu |
| Chemical Oxygen Demand | 15,000 mg/liter |

Table 5 **PERFORMANCE DURING LAUNDRY TEST No. 2**

| Time | Temperatures, $^oF$ | | | | | | | | Pressures (in. Hg abs) | | Total Power | Recovery Rate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (hr) | T-1 | T-2 | T-3 | T-4 | T-5 | T-6 | T-7 | T-8 | P-1 | P-2 | (kw) | (1/hr) |
| 0830 | 146 | --- | 162 | --- | --- | --- | --- | --- | 6.92 | 9.92 | 2.00 | Start |
| | | | | | | | | | | | | 6 |
| 0900 | 140 | 162 | 149 | 146 | 150 | 94 | 141 | 168 | 5.92 | 7.42 | 1.50 | |
| | | | | | | | | | | | | 16 |
| 0930 | 142 | 168 | 152 | 150 | 152 | 125 | 140 | 171 | 6.12 | 7.92 | 1.52 | |
| | | | | | | | | | | | | 16 |
| 1000 | 144 | 174 | 155 | 155 | 156 | 128 | 138 | 173 | 6.52 | 8.62 | 1.56 | |
| | | | | | | | | | | | | 20 |
| 1030 | 147 | 182 | 159 | 160 | 170 | 131 | 147 | 171 | 7.11 | 9.32 | 1.60 | |
| | | | | | | | | | | | | 18 |
| 1100 | 150 | --- | 162 | --- | --- | --- | --- | --- | 7.56 | 10.06 | 1.65 | |
| | | | | | | | | | | | | 24 |
| 1130 | 153 | 181 | 166 | 161 | 182 | 132 | 149 | 173 | 8.16 | 10.96 | 1.70 | |
| | | | | | | | | | | | | 16 |
| 1200 | 155 | 187 | 167 | 155 | 184 | 133 | 148 | 172 | 8.68 | 11.28 | 1.75 | |
| | | | | | | | | | | | | 22 |
| 1230 | 158 | 191 | 169 | 156 | 169 | 134 | 157 | 171 | 9.10 | 11.90 | 1.75 | |
| | | | | | | | | | | | | 20 |
| 1300 | 161 | 194 | 172 | 158 | 174 | 134 | 161 | 171 | 9.80 | 12.70 | 1.75 | |
| | | | | | | | | | | | | 16 |
| 1330 | 162 | 196 | 171 | 176 | 180 | 135 | 160 | 171 | 10.00 | 12.40 | 1.68 | |
| | | | | | | | | | | | | 24 |
| 1400 | 164 | --- | 173 | --- | --- | --- | --- | --- | 10.60 | 12.80 | 1.68 | |
| | | | | | | | | | | | | 22 |
| 1430 | 166 | --- | 174 | --- | --- | --- | --- | --- | 11.00 | 13.20 | 1.74 | End |

Table 6 PERFORMANCE DURING LAUNDRY TEST No. 20

| Time (hr) | Temperatures, °F | | | | | | | | Pressures (in. Hg abs) | | Total Power (kw) | Recovery Rate (1/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T-1 | T-2 | T-3 | T-4 | T-5 | T-6 | T-7 | T-8 | P-1 | P-2 | | |
| 0830 | 133 | --- | 133 | --- | --- | --- | --- | --- | 4.90 | 4.90 | --- | Start |
| 0900 | 130 | 142 | 140 | 131 | 143 | 114 | 135 | 161 | 4.50 | 5.90 | 1.50 | |
| 0930 | 132 | 150 | 143 | 132 | 144 | 118 | 138 | 159 | 4.80 | 6.30 | 1.50 | 16 |
| 1000 | 135 | 154 | 145 | 141 | 148 | 122 | 140 | 159 | 5.10 | 6.60 | 1.50 | 16 |
| 1030 | 138 | 160 | 147 | 147 | 159 | 125 | 142 | 159 | 5.52 | 7.02 | 1.50 | 14 |
| 1100 | 140 | 163 | 150 | 148 | 155 | --- | 138 | 158 | 5.92 | 7.52 | 1.50 | 18 |
| 1130 | 143 | 165 | 151 | 151 | 157 | 123 | 140 | 157 | 6.32 | 7.72 | 1.50 | 24 |
| 1200 | 145 | 171 | 154 | 157 | 155 | 127 | 145 | 158 | 6.72 | 8.30 | 1.55 | 24 |
| 1230 | 145 | 172 | 156 | 159 | 157 | 128 | 146 | 158 | 6.72 | 8.72 | 1.60 | 18 |
| 1300 | 148 | 177 | 158 | 164 | 162 | 129 | 149 | 159 | 7.22 | 9.32 | 1.60 | 24 |
| 1330 | 150 | 179 | 160 | 164 | 164 | --- | 150 | 159 | 7.52 | 9.72 | 1.65 | 24 |
| 1400 | 151 | 181 | 162 | 167 | 163 | 130 | 149 | 159 | 7.82 | 10.02 | 1.70 | 22 |
| 1420 | 151 | 182 | 162 | 150 | 163 | --- | 142 | 159 | 7.82 | 10.02 | 1.70 | 16<br>End |

Table 7 PERFORMANCE DURING LAUNDRY TEST No. 38

| Time (hr) | Temperatures, °F | | | | | | | | Pressures (in. Hg abs) | | Total Power (kw) | Recovery Rate (1/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T-1 | T-2 | T-3 | T-4 | T-5 | T-6 | T-7 | T-8 | P-1 | P-2 | | |
| 0900 | 128 | --- | 141 | --- | --- | --- | --- | --- | 4.22 | 6.12 | 1.69 | Start |
| 0930 | 131 | 153 | 142 | 139 | 151 | 140 | 138 | 156 | 4.62 | 6.22 | 1.60 | 10 |
| 1000 | 135 | 161 | 146 | 146 | 162 | 151 | 141 | 155 | 5.20 | 6.92 | 1.60 | 18 |
| 1030 | 141 | 170 | 152 | 155 | 167 | 157 | 143 | 155 | 6.00 | 8.00 | 1.65 | 24 |
| 1100 | 144 | 175 | 156 | 160 | 168 | 161 | 146 | 155 | 6.50 | 8.80 | 1.70 | 16 |
| 1130 | 148 | 182 | 161 | 168 | 174 | 162 | 144 | 154 | 7.20 | 9.80 | 1.78 | 20 |
| 1200 | 151 | 185 | 163 | 170 | 164 | 154 | 142 | 151 | 7.70 | 10.30 | 1.80 | 20 |
| 1230 | 153 | 189 | 164 | 172 | 166 | 161 | 150 | 150 | 8.20 | 10.60 | 1.84 | 26 |
| 1300 | 155 | 191 | 168 | 176 | 167 | 164 | 151 | 150 | 8.50 | 11.60 | 1.87 | 20 |
| 1330 | 158 | 196 | 170 | 181 | 172 | 170 | 156 | 151 | 9.20 | 12.30 | 1.90 | 24 |
| 1400 | 160 | 199 | 172 | 182 | 174 | --- | 150 | 153 | 9.60 | 12.90 | 1.90 | 26 |
| 1425 | 160 | 202 | 172 | 172 | 176 | --- | 151 | 156 | 9.60 | 12.90 | --- | 20<br>End |

155°F. The higher feed temperatures in run #2, resulting from the higher set point $T_8$, lowered the temperature difference between inlet and outlet liquor through the heat exchanger. This reduced the recovery rate and lengthened the run time.

The low specific energy obtained in run #20, 77.0 watt-hours per liter (291 watt-hours per gal), was the result of good purging of the non-condensibles from the condenser. With good purging, low pressure differentials, $\Delta P$, across the compressor can be maintained; therefore, the compressor shaft power is lower. These results were characteristic of runs 16 through 28 wherein the purge circuit was arranged as shown in Figure 19. The difference in this arrangement from the previous test runs is the addition of a vapor trap or condenser upstream of the needle valve. The condenser was formed from a 10-foot section of 3/4-inch diameter copper tubing into the shape shown in Figure 19, and mounted on the outside of the rear insulation panel. The condenser increased the air/vapor ratio entering the jet pump and effectively increased its purging capacity.

For test runs 30 through 38 a transfer tube was assembled to the jet pump discharge. This tube is shown in phantom in Figure 19. It was anticipated that the transfer tube would further improve the purging effectiveness. However, higher pressure differentials across the compressor were obtained after the transfer tube addition. This indicated that the tube diameter was too small causing a back pressure on the jet pump resulting in marginal purging performance.

It is noteworthy to compare the temperatures $T_5$ and $T_3$ in Tables 5, 6, and 7. It is seen that temperature $T_5$ is very close to the saturation temperature $T_3$. This indicates that the water droplets dripping off the condenser tubing effectively desuperheat the vapor as it enters the condenser shell. The degrees superheat, $T_2$-$T_3$, is shown to characteristically increase with time into the run. However, % superheat, defined as the change in enthalpy ($h_2$-$h_3$) compared to the latent heat of condensation, ($h_3$-$h_4$), at the saturation temperature, $T_3$, remains small. The % superheat gradually increases to 1% at the end of the run. With the purging technique used in Run #20, the % superheat is smaller, and does not exceed 0.8%.

## Synthetic MUST Brine

The second test series was performed using a synthetic waste. Since real wash water has a relatively low solids concentration, on the order of 1000 mg/liter (0.1%), a synthetic waste was required in order to evaluate the processor at high solids concentration within a reasonable test period. For this purpose the synthetic Medical Unit, Self-contained, Transportable (MUST) hospital composite waste was used at a concentration of 20X, which simulates the brine from an ultrafiltration and reverse osmosis system. The chemicals used to prepare 30 gallons of 20X MUST

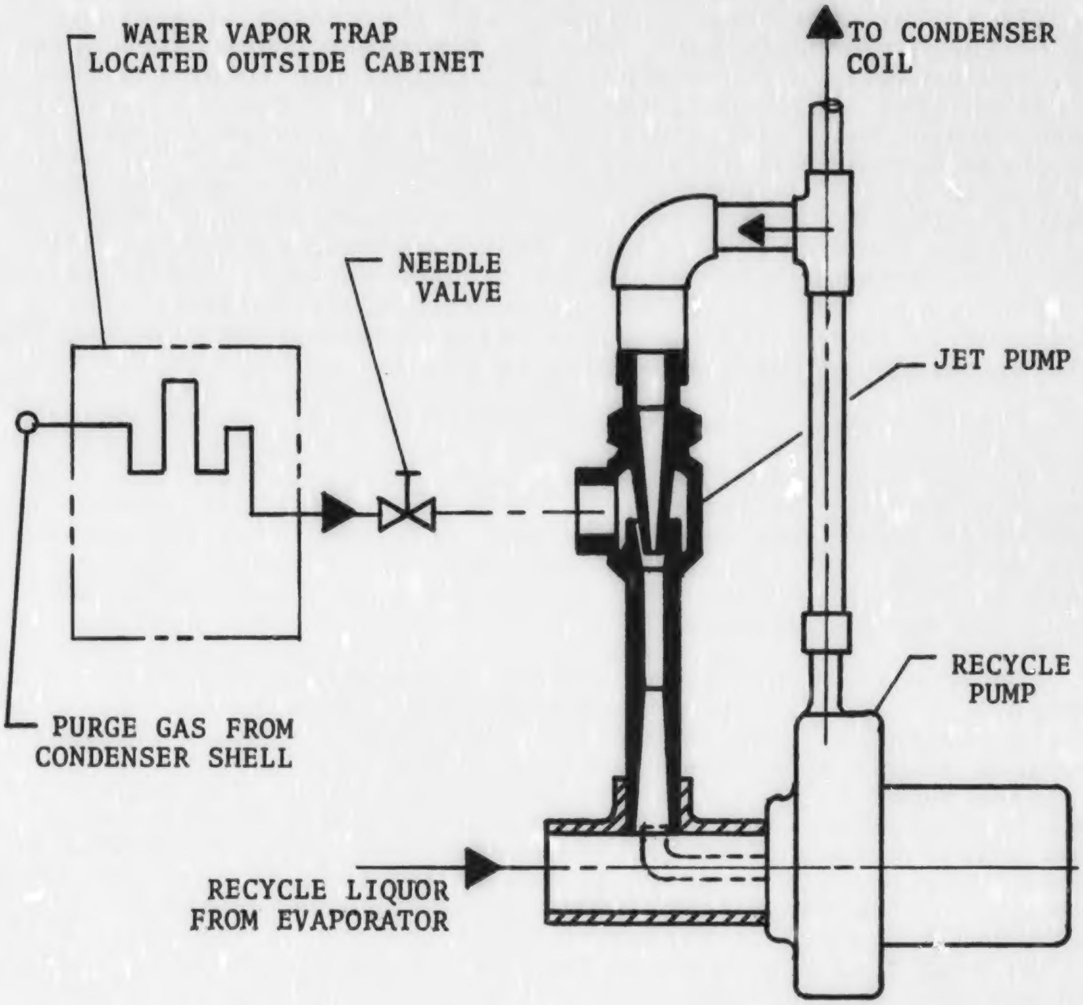
WATER VAPOR TRAP
LOCATED OUTSIDE CABINET
TO CONDENSER
COIL
NEEDLE
VALVE
JET PUMP
RECYCLE
PUMP
PURGE GAS FROM
CONDENSER SHELL
RECYCLE LIQUOR
FROM EVAPORATOR

Figure 19 JET-PUMP PURGING ARRANGEMENT

hospital composite waste each day were supplied by the Walden Research Division of Abcor Incorporated. The formulation is presented in Table 8; this brine has a solids concentration on the order of 2%.

Walden prepared the MUST constituents into twenty separate boxes - that is, each box contained the chemicals needed for 30 gallons of 20X solution so that at the end of the twenty test days the processor could be evaluated at a near 30% solids concentration. In Figure 20 is a photograph which shows the chemical groups corresponding to the constituents in Table 8 used to prepare the waste stream for each test run. The mixing procedure is presented as follows:

Group I -

Group I components are all solids. They were weighed-out together and mixed in first. These components were prepared by Walden with the exception of the human hair. The hair was obtained from a local barber shop and placed into plastic bags for storage until used.

Group II -

Group II components are liquids and gels. They were weighed-out together and mixed in seconds. This group was prepared entirely by Walden.

Group III through IX -

These components are all liquids. They were weighed-out in their respective groups except for the dichromate cleaning solution which was measured out separately and refrigerated. Chemicals which were weighed-out together were added to the waste stream in a random order.

Group X -

Group X components are gels and solids. The agars were obtained from Walden, prepared as gels, mixed together, placed in plastic containers and refrigerated.

Beef blood was obtained fresh, with sodium citrate added, from a local butcher. It was placed in plastic containers and refrigerated.

Dog food was obtained from Walden. It was weighed in plastic bags and refrigerated.

Urine was obtained daily from lab personnel, and refrigerated.

All components were added to the batch waste in random order.

## Table 8 SYNTHETIC BRINE FORMULA

| Group | Constituent | Concentration | |
|---|---|---|---|
| 1 | Detergent, Type 1 (FSN 7930-634-3935) | 4420. | mg/1 |
| | Sparkleen | 4040. | " |
| | Haema-Sol (Non-Sudsing Detergent) | 3940. | " |
| | Sodium Chloride | 3260. | " |
| | Hair | 2280. | " |
| | Shower/Lavatory Cleaner | 1010. | " |
| | Hand Soap (Lava) | 696. | " |
| | Scouring Powder (FSN 7930-205-0442) | 442. | " |
| | Talc | 202. | " |
| | Soil (Kaolinite) | 192. | " |
| | Silver Chloride | 143.2 | " |
| | Urea | 10.1 | " |
| 2 | Lysol (Undiluted) | 62.6 | ml/1 |
| | Insect Repellent (DEET) | 10.1 | " |
| | Deodorant | 10.1 | " |
| | Hair Dye | 10.1 | " |
| | Hair Coloring | 10.1 | " |
| | Hair Oil | 1516. | mg/1 |
| | Hair Gel | 374. | " |
| | Toothpaste | 374. | " |
| | Vegetable Oil | 352. | " |
| | Grease (Lard) | 234. | " |
| | Phisohex (Soap) | 173. | " |
| | Hair Shampoo | 50.6 | " |
| | Mouthwash | 20.2 | " |
| 3 | Betadine | 3780. | mg/1 |
| | Wescodyne | 712. | " |
| | Dichromate Cleaning Solution | 1258. | µl/1 |
| | Methyl Alcohol | 404. | " |
| | Acetone | 125.8 | " |
| 4 | Kodak X-Omat Developer | 18.84 | ml/1 |
| | Kodak X-Omat Fixer | 18.84 | " |

Table 8, Continued.

| Group | Constituent | Concentration | |
|---|---|---|---|
| 5 | Giemsa Stain | 150. | µl/l |
| | Wright Stain | 138.2 | " |
| | Crystal Violet Stain | 25.2 | " |
| | Safranin | 25.2 | " |
| | Immersion Oil | 12.58 | " |
| 6 | 1½% Thioglycolate | 628. | µg/l |
| | Sodium Chloride | 604. | " |
| | Zinc Sulfate | 414. | " |
| | 0.1 N Sodium Hydroxide | 454. | µl/l |
| | 5% Phenol Solution | 314. | " |
| | O-Toluidine Reagent | 69.2 | " |
| | Phenol Color Reagent | 37.6 | " |
| | Lithium Diluent | 37.6 | " |
| | Biurent Reagent | 31.4 | " |
| | Alkali-Hypochlorite Reagent | 25.2 | " |
| | Buffered Substrate | 25.2 | " |
| | 10% Formaldehyde | 25.2 | " |
| | KI-I Solution | 25.2 | " |
| | 22.2% Sodium Sulfate | 25.2 | " |
| | 3% Sulfosalicylic Acid | 25.2 | " |
| | Bilirubin Standard | 25.2 | " |
| | 30% Thichloroacetic | 18.82 | " |
| | 2% Sodium Citrate | 12.58 | " |
| | Diazo Reagent | 12.58 | " |
| | DNPH Color Developer | 12.58 | " |
| | Ether | 12.58 | " |
| 7 | Suspended Solids (Dog Food) | 2800. | mg/l |
| | Urine | 4260. | µl/l |
| | Blood (Animal) | 3660. | " |
| | 1½% Blood Agar | 414. | " |
| | 1½% Chocolate Agar | 414. | " |
| | 1½% EMB Agar | 414. | " |
| | 1½% Agar | 232. | " |
| | Spinal Fluid | 12.58 | " |

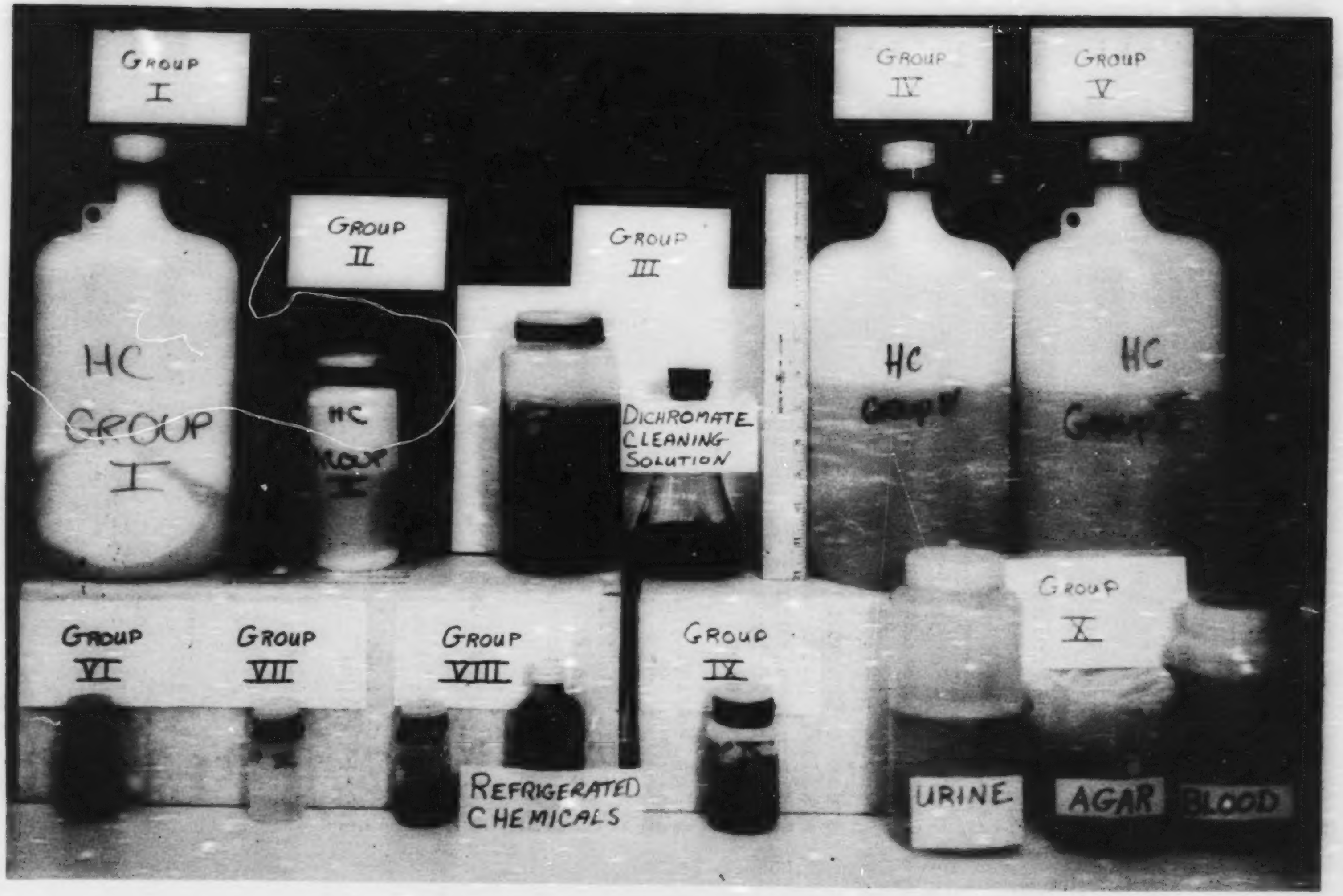
GROUP I
HC GROUP I
GROUP II
HC GROUP
GROUP III
DICHROMATE CLEANING SOLUTION
GROUP IV
HC
GROUP V
HC
GROUP VI
GROUP VII
GROUP VIII
REFRIGERATED CHEMICALS
GROUP IX
GROUP X
URINE
AGAR
BLOOD

Figure 20 DAILY SYNTHETIC BRINE INGREDIENTS

Spinal fluid was not added since it was impractical to obtain from local hospitals. Also, after the second test run dog food and hair were not included in the waste stream formula, since these ingredients were effectively removed by the lint filter in the sump (see Figure 19 and Table 1).

## Test Description

To initiate the test series the recycle loop and storage tank were filled with tap water, 131.8 liters and 263.1 liters, respectively. Thus, in the first day's test run tap water from storage was fed directly into the sump for processing in order to establish a base line. A run of three hours was conducted for this purpose.

Recycling of 20X MUST wastewater commenced on the second test day and continued for twenty test days. No additional tap water was added throughout the test series, nor was any antifoam agent added.

The twenty test days with the synthetic brine can be classified into seven modes dependent primarily on the preconditioning of the feed stock. These classifications are identified in Table 9. For modes 1 and 2 the test set-up is shown in Figure 21. The 20X MUST constituents were mixed with recycled product water to make a 30 gallon solution within a calibrated polyethylene container and pumped directly into the sump for processing. For the remainder of the tests, modes 3 through 7, the test set-up is shown in Figure 22. In this arrangement the storage tank was used as a preconditioning chamber. The feed stock solution from the polyethylene tank was pumped directly into the storage tank the evening previous to each test day. The storage tank was maintained under vacuum pressure via a peristaltic pump which continuously purged the evolved gases for a period of 12 hours or more between test runs. Modes 3 through 7 are distinguished by different set point temperatures of the thermostatically controlled heater in the storage tank. As indicated in Table 9 preconditioning temperatures of 160°F and 85°F were evaluated. In modes 6 and 7, photochemicals (groups 4 and 5 in Figure 20) were not added to the feed stock.

During each test run thermodynamic data was recorded regularly at ½ hour intervals - and daily water samples of the feed, concentrate, and condensate were taken at specific times into the run. In addition, hourly test tube samples were taken of the product water during modes 3 through 7 in order to record variations in turbidity within each test run.

Near the end of the fifth test day (Mode 2), 5½ hours into the run, gross foam carry-over through the compressor occurred. The unit was shut-down and subsequent start-up was prevented due to a locked compressor rotor. Inspection of the compressor drive also revealed gross deterioration of the motor insulation, and gross peeling-off of the paint on the motor and compressor frames. Also, loose rust particles covered the surfaces of the compressor drive mounting plates (condenser cover plate). The probable cause of the rotor locking was rust particles entering the suction side of the compressor and wedging into the close clearance between the rotary lobes. The compressor was easily freed on the bench with a strap wrench applied to the drive pulley. No mechanical damage of the lobes or timing gears occurred. Before the start of the next test run the compressor motor was rewound with class H insulation (the original winding had a class F rating) and the test set-up was rearranged as shown in Figure 22.

No further foam carry-over was evident for the remainder of the test series, consecutive test runs 6 through 21. However, on the last test day, run #21, near the end of the test approximately six hours into the run another compressor drive failure occurred. Subsequent inspection revealed that the compressor rotor had locked, and there was a short to ground in the motor winding. Visual inspection of the motor, however, did not reveal any heat deterioration of the stator insulation.

## Test Results

The daily water analyses performed during the synthetic brine tests are summarized in Table 10; these data were obtained in the CHEMTRIC laboratory - except for the TOC data, which the Nalco Chemical Company determined. The results of detailed analyses performed by Nalco on raw condensate samples taken during runs 10, 15, and 18 are presented in Table 11.

The condensate total solids data presented in Table 10 indicate that during the initial tests foam was being carried over from the evaporator into the condenser. After the fifth test, when the feed was always degassed overnight in the storage tank, the turbidity data indicates that degassing eliminated or at least reduced the foam carry-over problem. After the seventh test the total solids data indicate that the problem had definitely been eliminated or reduced to an insignificant level (i.e., TS <40 ppm except for test #12). The condensate total solids level was still high during tests #6 and #7 because the condenser had been contaminated during the previous test days by foam carry-over, and the flushing action of fresh condensate during tests #6 and #7 was required to clean the condenser surfaces.

After the foaming problem was resolved by degassing the feed, the specific resistance and the organic content of the condensate were still excessively high. Reducing the degassing temperature (i.e., increasing the vacuum) and finally eliminating the addition of fresh photochemicals did not improve the condensate quality. Instead, the quality continued to degrade - but this is attributed to the fact that the concentration of solids in the concentrate (recycle liquor) was continuously increased during this period from 0.05 to 0.293.

Table 9 SYNTHETIC BRINE TEST MODES

| Mode | Test Runs | Description |
|---|---|---|
| 1 | 1 thru 4 | Test set-up per Figure 21 - feed stock prepared morning of test and added directly to sump - no degassing. |
| 2 | 5 | Test set-up per Figure 21 - feed stock prepared previous evening and heated in polyethelene tank over night (250 watts) for 12 hours. |
| 3 | 6 thru 10 | Test set-up per Figure 22 - feed stock prepared previous evening and heated in storage tank under saturation conditions - temperature set point @ 160°F. |
| 4 | 11 thru 15 | Test set-up per Figure 22 and mode 3 - but temperature set point @ 135°F - door on cabinet removed for entire test run. |
| 5 | 16 thru 18 | Test set-up per Figure 22 and mode 3 - but no power to storage tank heater - door and top insulation panel removed for entire test run - storage tank temperature at 85°F. |
| 6 | 19 thru 20 | Test set-up per Figure 22 and mode 5 - but no photo chemicals added to feed stock. |
| 7 | 21 | Test set-up per Figure 22 and mode 6 - but temperature of storage tank maintained at 160°F. |

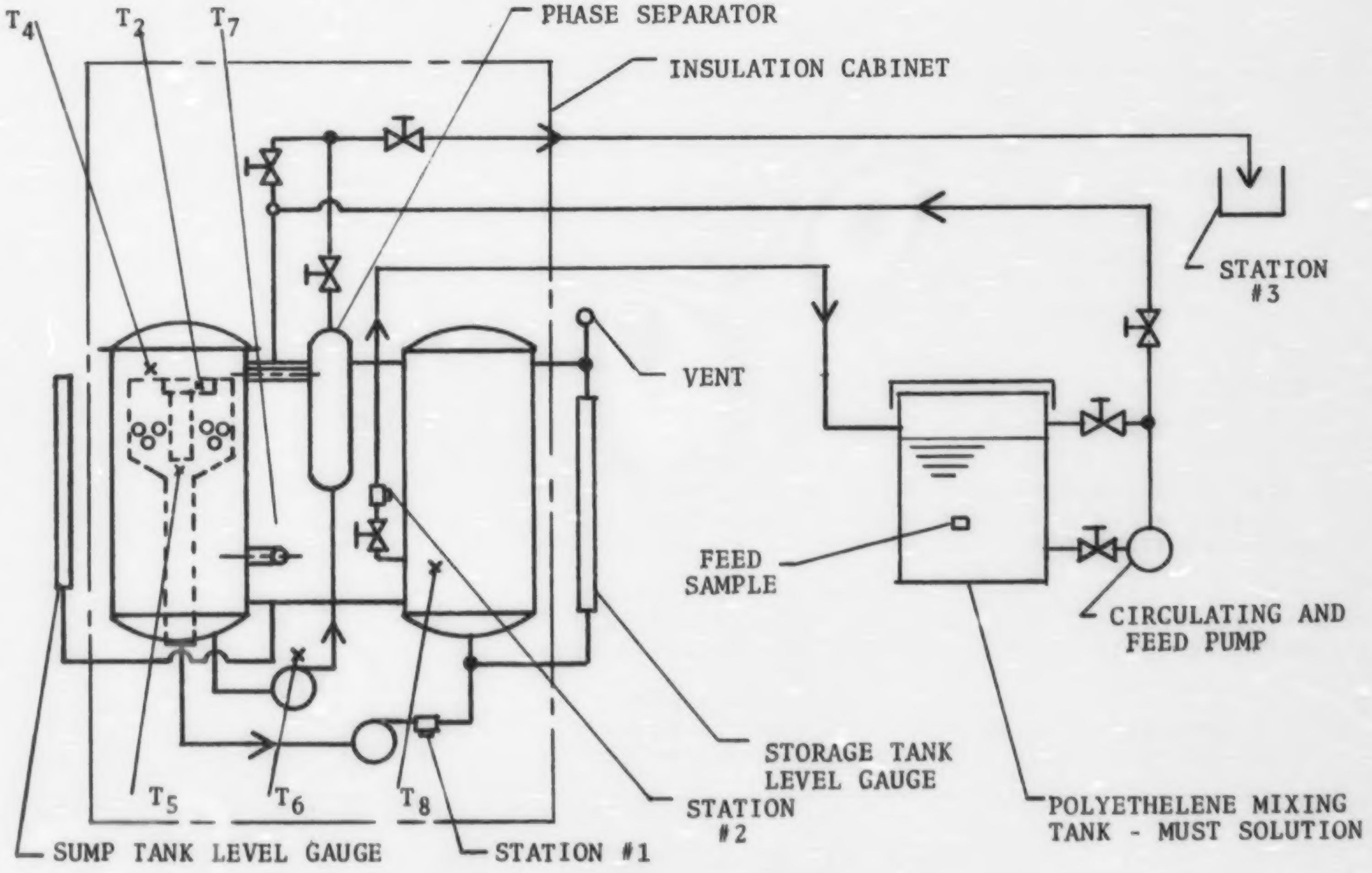
T4
T2
T7
PHASE SEPARATOR
INSULATION CABINET
STATION #3
VENT
FEED SAMPLE
CIRCULATING AND FEED PUMP
STORAGE TANK LEVEL GAUGE
STATION #2
POLYETHELENE MIXING TANK - MUST SOLUTION
T5
T6
T8
SUMP TANK LEVEL GAUGE
STATION #1

Figure 21 SYNTHETIC BRINE TEST INITIAL ARRANGEMENT

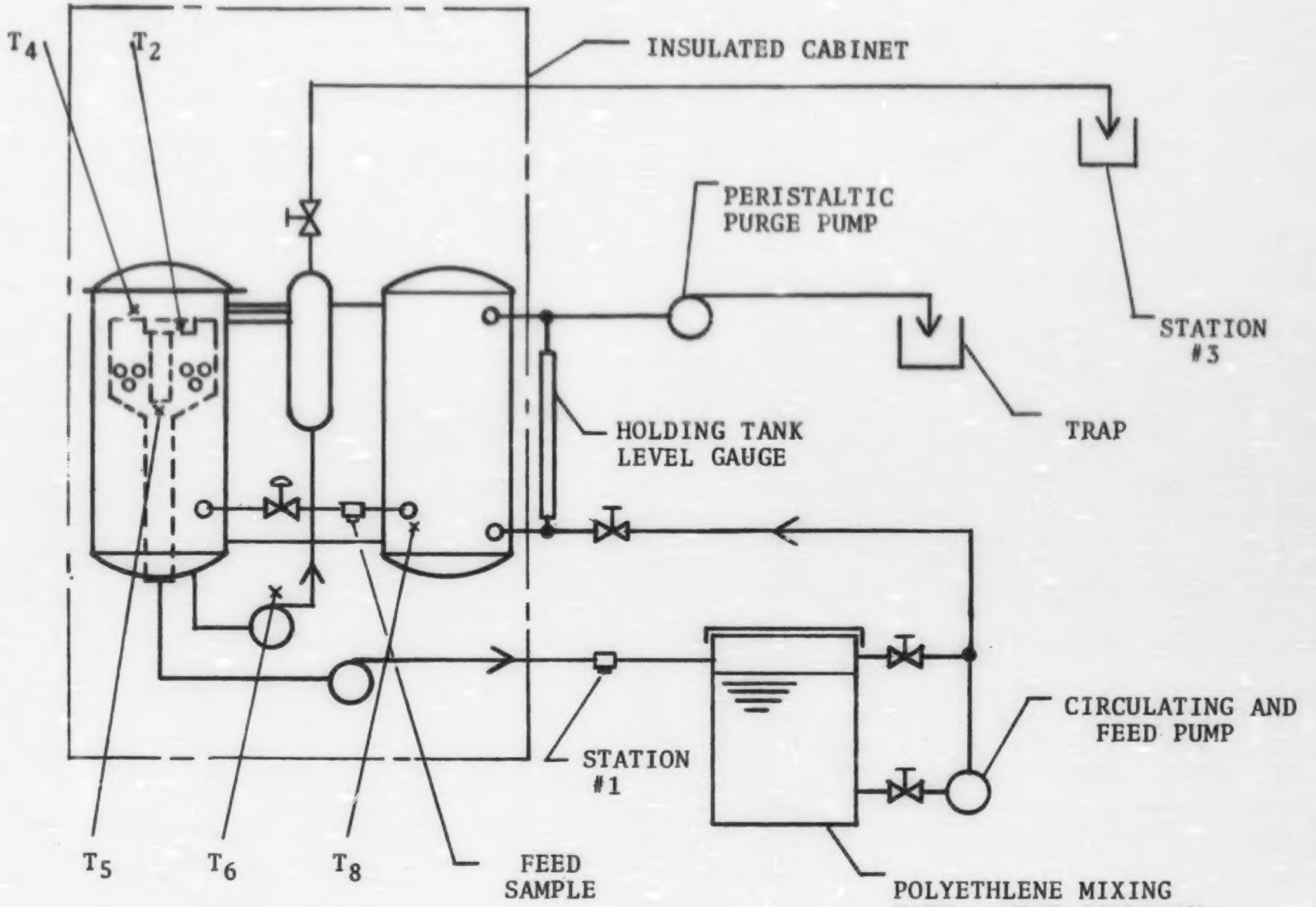
T4
T2
INSULATED CABINET
PERISTALTIC PURGE PUMP
STATION #3
TRAP
HOLDING TANK LEVEL GAUGE
CIRCULATING AND FEED PUMP
STATION #1
T5
T6
T8
FEED SAMPLE
POLYETHLENE MIXING TANK - MUST SOLUTION

Figure 22 SYNTHETIC BRINE TEST FINAL ARRANGEMENT

Table 10 SYNTHETIC BRINE TEST DAILY ANALYSES

| Test No.& Mode | Total Solids (%) | | | Sterile (+/-) | | pH (units) | | Turbidity (Jtu) | | Sp. Res. (ohm-cm) | | COD (mg/1x10$^{-3}$) | | | | TOC (mg/1) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Feed | S-1* | S-3 | S-1 | S-2 | S-1 | S-2 | S-1 | S-2 | S-1 | S-2 | Feed | S-1 | S-2 | S-3 | S-1 |
| 01-1 | NST+ | NST | NST | NST | NST | 5.6 | NST | 4 | NST | NST | NST | NST | 0.1 | NST | 0.6 | NST |
| 02-1 | 2.41 | .017 | 0.6 | --- | --- | 8.9 | 7.2 | 16 | 3 | 720 | 3700 | 20.0 | 0.9 | 0.1 | 6.0 | 210 |
| 03-1 | 1.57 | .012 | 2.0 | --- | --- | 9.0 | 8.8 | 18 | 7 | 240 | 980 | 21.0 | <2.0 | 0.6 | 16.0 | 610 |
| 04-1 | 1.69 | .014 | 3.6 | --- | --- | 9.3 | 9.0 | 20 | 12 | 300 | 550 | 19.0 | 1.9 | 1.0 | 25.0 | 640 |
| 05-2 | 2.42 | .012 | 4.9 | --- | NST | 9.3 | NST | 25 | NST | 400 | NST | 22.0 | <1.0 | NST | 37.5 | NST |
| 06-3 | 5.77 | .014 | 5.0 | --- | NST | 9.4 | NST | 10 | NST | 660 | NST | 24.0 | 1.4 | NST | 34.0 | 360 |
| 07-3 | 3.06 | .010 | 6.6 | --- | " | 9.4 | " | 10 | " | 580 | " | 29.5 | 1.1 | " | 57.5 | 470 |
| 08-3 | 2.78 | .002 | 9.0 | --- | " | 9.6 | " | 12 | " | 560 | " | 26.5 | <2.0 | " | 72.5 | 700 |
| 09-3 | 2.53 | .002 | 15.3 | --- | " | 9.7 | " | 16 | " | 450 | " | 26.5 | 1.0 | " | 114. | 870 |
| 10-3 | 2.67 | .003 | 14.6 | --- | " | 9.6 | " | 11 | " | 480 | " | 25.5 | 2.7 | " | 118. | 720 |
| 11-4 | 2.68 | .002 | 15.0 | +-- | NST | 9.6 | NST | 6 | NST | 560 | NST | 27.5 | 2.1 | NST | 142. | 550 |
| 12-4 | 2.74 | .011 | 16.0 | --- | " | 9.6 | " | 8 | " | 400 | " | 26.5 | 2.9 | " | 154. | 740 |
| 13-4 | 2.81 | .001 | 18.1 | --- | " | 9.4 | " | 8 | " | 340 | " | 24.5 | 3.1 | " | 150. | 970 |
| 14-4 | 2.91 | .004 | 19.3 | --- | " | 9.4 | " | 10 | " | 300 | " | 24.5 | 3.3 | " | 174. | 2100 |
| 15-4 | 2.90 | .001 | 21.2 | --- | " | 9.4 | " | 10 | " | 300 | " | 26.5 | 3.8 | " | 190. | 1000 |
| 16-5 | 3.00 | .001 | 22.2 | --- | NST | 9.1 | NST | 10 | NST | 250 | NST | 24.5 | 4.0 | NST | 192. | 2400 |
| 17-5 | 3.58 | .001 | 22.7 | --- | " | 9.1 | " | 12 | " | 200 | " | 36.5 | 4.6 | " | 206. | 1400 |
| 18-5 | 4.04 | .001 | 23.2 | --- | " | 9.4 | " | 10 | " | 240 | " | 39.5 | 4.8 | " | 222. | 1300 |
| 19-6 | 4.26 | .004 | 25.2 | --- | NST | 9.4 | NST | 10 | NST | 210 | NST | 38.5 | 5.2 | NST | 224. | 1500 |
| 20-6 | 4.44 | .003 | 28.0 | --- | " | 9.1 | " | 11 | " | 150 | " | 43.0 | 5.9 | " | 248. | 1600 |
| 21-7 | 4.91 | NST | 29.3 | NST | NST | 9.6 | NST | 17 | NST | 320 | NST | 48.0 | 4.4 | NST | 256. | NST |

* S-1, S-2 and S-3 refer to sample points (see figures 21 and 22).
+ No sample taken.

Table 11 SYNTHETIC BRINE TEST DETAILED ANALYSES

| Item | Nalco Measurements, mg/1 | | | U.S. PHS Limit | |
|---|---|---|---|---|---|
| | Test #10 | Test #15 | Test #18 | | |
| Metals: | | | | | |
| Barium(Ba), Soluble & Insoluble | <0.5 | <0.5 | <0.5 | 1.0 | mg/1 |
| Cadmium(Cd), " " " | <0.01 | 0.01 | 0.02 | 0.01 | " |
| Chromium(Cr), Hexavalent | <0.1 | <0.1 | <0.1 | 0.05 | " |
| Copper(Cu), Soluble & Insoluble | 0.25 | 0.30 | 2.8 | 1.0 | " |
| Iron(Fe), " " " | <0.1 | <0.1 | 0.2 | 0.3 | " |
| Lead(Pb), " " " | <0.1 | 0.1 | <0.1 | 0.05 | " |
| Magnesium(Mg), Soluble & Insoluble | <0.02 | 0.02 | <0.02 | NS* | |
| Manganese(Mn), " " " | <0.05 | <0.05 | <0.05 | 0.05 | " |
| Silver(Ag), " " " | <0.01 | <0.01 | 0.01 | 0.05 | " |
| Other Parameters: | | | | | |
| Ammonia(N) | 740. | 1000. | 1400. | NS* | |
| Arsenic(As), Soluble & Insoluble | <0.001 | <0.001 | <0.002 | 0.05 | mg/1 |
| Chloride(Cl) | 470. | 150. | 1. | 250. | " |
| Cyanide(CN), Free & Combined | <0.01 | <0.01 | <0.01 | 0.2 | " |
| Fluoride(F), " " " | <0.05 | <0.05 | <0.05 | 0.8 | " |
| Methylene Blue Active Substances | 0.22 | 0.38 | 0.32 | 0.5 | " |
| Nitrate(N) | <0.2 | <0.2 | <0.2 | 45. | " |
| Phenols(Phenol-C6H5OH) | 120. | 150. | 160. | 0.001 | " |
| Selenium(Se), Soluble & Insoluble | <0.002 | <0.001 | <0.002 | 0.01 | " |
| Sulfate(S) | 6. | 1.9 | 3. | 250. | " |
| Total Organic Carbon | 720. | 1000. | 1300. | NS* | |

* Not Specified.

Table 11 indicates that the condensate had a very strong ammonia odor, and excessive amounts of chlorides and phenols. The major source of these constituents was undoubtedly the Kodak developer and fixer used to simulate wastes from an X-ray film processor in a hospital laboratory. Thus, if these wastes had not been added to the synthetic brine the quality of the recovered water would have been substantially higher. Similarly, if the pH of the feed had been adjusted to "fix" the ammonia, the chloride and ammonia levels would have been near acceptable values.

The high ammonia, chlorides and phenol levels do not explain the excessively high COD and TOC levels presented in Table 11. Identification of the source of these organics was undertaken by the Environmental Chemistry Branch at Fort Detrick; their results are presented in Table 12, along with the TOC determinations made by the Nalco Chemical Company. As seen in this table, nearly two-thirds of the TOC is due to organics which co-distill with water at the conditions present in the Recycler/Heater. The other third is apparently phenols and trace organics.

Identification of the condenser gases was attempted by pumping a portion of the condenser purge gases into a sample bottle, per the Standard Methods procedure for collecting sludge digester gas, during one of the mode 3, 4 and 6 tests. These samples were sent to All-Tec Associates in Arlington Heights, Illinois for chromatographic determination of their oxygen, nitrogen, methane, ammonia and carbon dioxide content. The results obtained are presented in Table 13.

Table 12 COMPARISON OF ORGANICS DETERMINATIONS

| Test No. | Fort Detrick Data, mg/l | | | | | Nalco* TOC (mg/l) |
|---|---|---|---|---|---|---|
| | Methyl Alcohol + | Ethyl Alcohol + | Acetone + | Isopropyl Alcohol = | Sum Total | |
| 02 | 112 | 40 | 7 | 0 | 159 | 210 |
| 03 | 251 | 113 | 66 | 4 | 434 | 610 |
| 04 | 244 | 105 | 50 | 4 | 403 | 640 |
| 05 | --- No | --- Sample | -- Taken | --- | --- | --- |
| 06 | 170 | 64 | 10 | 2 | 246 | 360 |
| 07 | 219 | 84 | 12 | 3 | 318 | 470 |
| 08 | 269 | 107 | 18 | 3 | 397 | 700 |
| 09 | 403 | 129 | 16 | 3 | 551 | 870 |
| 10 | 305 | 116 | 17 | 3 | 441 | 720 |
| 11 | 270 | 94 | 7 | 2 | 373 | 550 |
| 12 | 388 | 155 | 20 | 4 | 567 | 740 |
| 13 | 420 | 190 | 32 | 4 | 646 | 970 |
| 14 | 449 | 165 | 22 | 4 | 640 | 2100 |
| 15 | 548 | 169 | 20 | 4 | 741 | 1000 |
| 16 | 627 | 226 | 49 | 5 | 907 | 2400 |
| 17 | 713 | 281 | 71 | 7 | 1072 | 1400 |
| 18 | 755 | 326 | 92 | 8 | 1181 | 1300 |
| 19 | 738 | 357 | 109 | 9 | 1213 | 1500 |
| 20 | 447 | 334 | 94 | 8 | 883 | 1600 |

Fraction Identified by Fort Detrick = 0.615 = 11172 / 18140

* TOC Data Determined by Nalco Chemical Company

## Table 13 PURGE GAS ANALYSES

| Test No. | Oxygen | Nitrogen | Methane | Undetermined |
|---|---|---|---|---|
| 9 | 19.0% | 77.5% | 3.5% | 0.0% |
| 15 | 2.6 | 9.4 | 54.0 | 34.0% |
| 20 | ---------Sample Bottle Broken In Transit--------- | | | |

The results obtained from the Test 9 sample were as expected - because highly soluble gases such as ammonia should be absorbed by condensate on the heat exchanger before the purge gases are drawn from the condenser. Conversely, the large percentage of methane and undetermined gases in the Test 15 sample was unexpected. Apparently, methane and other non-condensible gases were being evolved in the storage tank - so that purge gases drawn through the storage tank were diluted with these gases prior to the sample bottle. In both cases, the volumetric flow rate of non-condensible gases was relatively low - because the peristaltic purge pump which has a displacement of 1000 cc/min is capable of maintaining the required condenser pressure.

Mechanical performance data during the MUST waste stream tests are given in Table 14 and 15. Table 14 represents data during Test #1 with tap water; Table 15 contains the data recorded during Test #21, which concluded the test series with a total dissolved solids concentration of 29.3%. It is seen that at the same operating temperature, $T_1$, the recovery rate at 29.3% solids is 30% lower than the tap water baseline rate.

Upon completion of the brine tests the flanged head was removed and the compressor drive, relief valve, condenser cover plate, condenser coil assembly, and spray ring assembly were removed for inspection and cleaning. There was no mechanical damage to any components; however two spray nozzles were completely plugged with lint material which was protruding into the 3/4-inch diameter ring manifold. Hence, the lower recovery rate baseline can be attributed to nozzle blockage. The lint material was evidently left-over from the laundry water tests and had accumulated in the nozzles to form a plug during the synthetic brine tests.

## Table 14 PERFORMANCE DURING BRINE TEST No. 1

| Time (hr) | Temperatures, °F | | | | | | | | Pressures (in. Hg abs) | | Total Power (kw) | Recovery Rate (1/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T-1 | T-2 | T-3 | T-4 | T-5 | T-6 | T-7 | T-8 | P-1 | P-2 | | |
| 1500 | 137 | 168 | 146 | 154 | 155 | 140 | 141 | 156 | 5.4 | 6.9 | 1.40 | Start<br>16.0 |
| 1530 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---- | 16.0 |
| 1600 | 140 | 171 | 149 | 155 | 155 | --- | 143 | 158 | 5.9 | 7.4 | 1.45 | 16.5 |
| 1630 | 141 | 174 | 154 | 159 | 159 | 144 | 146 | 158 | 6.0 | 8.3 | 1.60 | 16.6 |
| 1700 | 144 | 181 | 157 | 164 | 162 | 147 | 149 | 160 | 6.6 | 8.9 | 1.70 | 17.5 |
| 1730 | --- | 184 | --- | 166 | 165 | 142 | 151 | 159 | --- | --- | ---- | 19.2 |
| 1800 | 148 | 184 | 161 | 167 | 168 | --- | 151 | 158 | 7.2 | 9.8 | 1.70 | End |

## Table 15 PERFORMANCE DURING BRINE TEST No. 21

| Time (hr) | Temperatures, °F | | | | | | | | Pressures (in. Hg abs) | | Total Power (kw) | Recovery Rate (1/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T-1 | T-2 | T-3 | T-4 | T-5 | T-6 | T-7 | T-8 | P-1 | P-2 | | |
| 0940 | 129 | --- | 150 | --- | --- | --- | --- | --- | 4.4 | 7.6 | 1.70 | Start<br>9.6 |
| 1000 | 128 | 157 | 145 | 142 | 163 | 125 | 131 | 159 | 4.3 | 6.6 | 1.53 | 11.1 |
| 1030 | 132 | 169 | 154 | 151 | 170 | 140 | 133 | 159 | 4.8 | 8.3 | 1.73 | 12.0 |
| 1100 | 137 | 181 | 154 | 166 | 179 | 148 | 135 | 160 | 5.4 | 8.3 | 1.54 | 12.8 |
| 1130 | 143 | 187 | 161 | 176 | 187 | 151 | 138 | 159 | 6.4 | 10.0 | 1.56 | 13.5 |
| 1200 | 145 | 195 | 162 | 181 | 184 | 116* | 141 | 162 | 6.7 | 10.2 | 1.52 | 13.5 |
| 1230 | 147 | 199 | 164 | 177 | 164 | 101 | 140 | 161 | 7.0 | 10.6 | 1.51 | 12.9 |
| 1300 | 148 | 201 | 166 | 179 | 164 | 103 | 142 | 162 | 7.2 | 11.2 | 1.55 | ---- |
| 1330 | --- | 202 | --- | --- | 164 | 107 | 143 | 162 | --- | ---- | ---- | 13.2 |
| 1400 | 150 | 203 | 167 | 180 | 167 | 107 | 143 | 162 | 7.5 | 11.5 | 1.53 | ---- |
| 1420 | --- | --- | --- | --- | --- | --- | --- | --- | --- | ---- | ---- | End |

* Cabinet door removed

# SECTION VII

## DISCUSSION OF RESULTS

### Design

The test results indicate that the processor tank temperature ranges from less than 165°F during standby (e.g., overnight) to more than 165°F after several hours of continuous operation. This characteristic causes the "starting" recovery rate to be lower than 6 gph - and the steady-state load on the compressor motor to be too high. Future designs should include (1) a standby heater in the process tank, if a fast start-up is required, and (2) less insulation or a thermostatically-controlled cabinet-ventilation fan.

These tests have also demonstrated the need for a lint filter when processing real laundry wastewater. Long fibers tend to coalesce and plug the spray nozzles (0.53 cm) in the evaporator and the jet pump nozzle (0.31 cm). Also, for quick accessibility to the compressor drive, a V-retainer coupling flange instead of the bolted flange used in the prototype design would provide much easier and faster removal of the tank head; this together with a thinner gage (12 gage) material for the head would provide a lighter assembly weight, on the order of 25 lbs (11.3 kg). According to the manufacturer's recommended lubrication requirements the compressor drive should be inspected (hence the head must be removed) every three months based on an 8-hour day, 5 day per week operation of the Recycler.

Regarding the compressor motor, for long service life the single phase capacitor start motor should utilize an external relay instead of an internal centrifugal starter switch; this relay could be located with the capacitor outside the compressor tank. Also, the main motor winding insulation (i.e., the ground insulation in the slots and wedges of the stator) should be Nomex (DuPont); the strand insulation on the wire should be high-temperature (220°C), polyamide resin material similar to Pyre-ML magnet wire manufactured by Rea Magnet Wire Company; lead wire insulation between coils should be a glass braid tape material. This type of insulation system is not uncommon nor is it too costly.

The importance of good purging technigue was clearly demonstrated during this test program. Keeping the condenser shell adequately free of air and other non-condensible gases results in a low specific energy requirement, which is very close to that predicted by the analysis presented in Section 4. The predicted power requirement was 1798 watts based on a recovery rate of 6 gallons (22.7 liters) per hour; this equals a specific energy of 79.2 watt-hours per liter. The measured values during laundry water Test #20, in which an improved purge technique was used, indicate that the average specific energy was 77.0 watt-hours per liter. On the last test run, Test #38, with the processor operating at 2.5% total dissolved solids the average specific energy is 10% higher than the predicted steady state value; however, as explained in Section VI under Test Results, purging was marginal.

These tests have also shown that corrosion presents a problem, and corrosion resistant materials are required with the MUST feed if degassing is not effectively accomplished. At the higher processing temperatures required for higher recovery rates, the chloride content in the ammonia chloride carry-over increases and its reaction with water vapor to form hydrochloric acid can be quite corrosive.

## Water Quality

Since there are no published standards per se for wash water it is necessary to refer to the 1962 Drinking Water Standards published by the Public Health Service. This is done in Table 3 wherein the analytical data obtained from Laundry Test #32 is compared to the Standards. The analytical data obtained from Brine Test #10, 15 and 18 are presented in Table 11 for comparison. It is seen that the product water from both the laundry water and brine tests can be classified as soft since the total solids content is well below 75 mg/l. Also, in both cases the product water was sterile. Regarding the product water from the laundry water tests, the water was clear but would not be considered potable due to the organic content of 20 mg/l and ammonia content of 16 mg/l. For use as wash water this order of magnitude of TOC should be harmless; also, the product water did not have an objectionable odor due to the ammonia content.

Regarding the product water from the brine tests, though an 88% reduction in COD was achieved for example in Test #18, the magnitude of TOC was still very high (1300 mg/l) due to the very high organic content of the feed stock. The feed stock TOC was not measured but its magnitude can be assessed by use of the average COD:TOC ratio of 3.1 computed from sixteen values of COD and TOC given in Table 10 for condensate samples (TOC values for tests No. 14 and 16 were not used in the computation since these were considered too high). Since the degassed feed COD was 39, 500 mg/l, the TOC value was on the order of 13,000 mg/l. The turbidity of the feed was well beyond 1000 Jtu. The product water was very clear in comparison having a turbidity of 10 Jtu; however, it had characteristically a slight cloudy appearance and a strong ammonia odor. It is interesting to point out that fixed (acified to a pH of 2) samples of the product water stored in quart jars sealed with aluminum foil became very clear in appearance and a spot measurement revealed a gross reduction in turbidity to a value less than 1 Jtu. This was evidently due to the gradual escape of soluable gases. Results of these tests have indicated that the processor had concentrated the simulated brine discharged from the MUST water treatment system to at least 15X. A gross reduction of the TOC and ammonia in the recovered water, however, must be accomplished by a more effective pretreatment of the feed stock such as extended aeration.

## SECTION VIII

## ECONOMIC ASSESSMENT

The Recycler/Heater developed under this program reflects a concern for design details that are required to achieve a steady-state process rate of 22.7 liters/hr (6 gph) and a specific energy draw of 79 watt-hours/liter, within a self-contained package which requires a minimum of floor space. During the test phase, the operational conditions, control specifications, and maintainence requirements were defined. With these data it is possible to estimate the actual annual cost of this type of self-contained water recovery appliance, and compare these costs to water and disposal costs to predict the potential demand.

### Total Annual Costs

Actual manufacturing costs are difficult to ascertain because they are dependent on production volume, facilities, equipment, and experience. For the purpose of a cost projection, however, baseline costs were estimated by taking the confirmed Parts List of the prototype assembly and soliciting quotations on each component as a function of quantity purchased. This should provide an accurate baseline in today's dollars since most of the components are purchased parts which are already production items. It should be noted that the cost quotations on purchased parts were solicited only from those vendors who supplied the same components used in the prototype assemblies. Since most of these suppliers were unable to quote on mass production quantities, the lower quantity costs were extrapolated to estimate the cost of 10,000 and 1,000,000 units per year.

Table 16 presents the detailed cost figures for the Recycler/Heater unit in quantities from 1 unit to 1,000,000 units per year. The assumptions used in the cost analyses are that the unit would be assembled and tested at the manufacturer's plant - and shipped to a local distributor or contractor in three parts (i.e., the processor tank assembly, holding tank, and hot water storage tank). The distributor would handle the local installation. The estimated installed costs, which include a 33-1/3% G&A cost and a 50% profit and commission allowance, are shown to vary from a high of $8812 per single unit production per year to $5098 for the production of 1,000,000 units per year.

Operating costs are based only on the cost of replacement parts on the assumption that the compressor drive should be completely overhauled and the mechanical seals in the recycle and

## Table 16 PROJECTED COST OF RECYCLER/HEATER

| Cost Item | Annual Production Rate | | | |
|---|---|---|---|---|
| | 1 | 100 | 10,000 | 1,000,000 |
| Vapor Compressor | $ 279 | $ 228 | $ 200 | $ 150 |
| Compressor Motor | 118 | 90 | 80 | 70 |
| Relief Valve | 32 | 26 | 21 | 17 |
| Recycle Pump & Motor | 160 | 135 | 115 | 100 |
| Condensate Pump | 52 | 33 | 24 | 20 |
| Pulleys & V-belt | 20 | 16 | 13 | 11 |
| Feed Valve | 76 | 47 | 33 | 26 |
| Jet Pump | 47 | 42 | 40 | 39 |
| Tank Heater | 40 | 28 | 22 | 19 |
| Level Controller | 112 | 70 | 50 | 40 |
| Vacuum Switch | 17 | 16 | 15 | 14 |
| Delta P Swtich | 65 | 57 | 53 | 51 |
| Pressure Switch | 4 | 4 | 3 | 3 |
| Sump Level Switch | 8 | 8 | 7 | 6 |
| Sump Piping | 14 | 13 | 12 | 11 |
| Condenser Coil | 105 | 87 | 78 | 74 |
| Spray Ring | 50 | 40 | 35 | 33 |
| Spray Nozzles | 10 | 7 | 5 | 4 |
| Tank Weldments | 1585 | 1275 | 1125 | 1000 |
| Tank Flanges | 20 | 10 | 6 | 5 |
| V-Band Clamp | 44 | 20 | 12 | 8 |
| Demister Material | 40 | 30 | 20 | 10 |
| Condensate Pump Motor | 23 | 18 | 16 | 15 |
| Insulation | 126 | 113 | 100 | 87 |
| Miscellaneous Plumbing | 225 | 202 | 180 | 160 |
| Electrical Suppliers | 104 | 94 | 84 | 74 |
| Assembly Labor & O'H'D. | 800 | 640 | 480 | 320 |
| Packing & Shipping | 180 | 164 | 148 | 132 |
| Total | $4356 | $3513 | $2977 | $2499 |
| G&A Expense (33-1/3%) | 1452 | 1171 | 992 | 833 |
| Total Manufacturing Cost | $5808 | $4684 | $3969 | $3332 |
| Profit & Discounts (50%) | 2904 | 2342 | 1984 | 1666 |
| Installation Cost | 100 | 100 | 100 | 100 |
| Installed Cost | $8812 | $8126 | $6053 | $5098 |
| Average Cost* | $ 899 | $ 829 | $ 617 | $ 520 |
| Annual Maintenance | 100 | 100 | 100 | 100 |
| Total Annual Cost | $ 999 | $ 929 | $ 717 | $ 620 |

* Ammortized over 20 years @ 8%/year

condensate pumps replaced every 30 months, and that the unit is operated for 140 hours each week. It is assumed that this maintenance would be handled by the local dealer and that labor costs would be covered by a five year renewable service guarantee issued by the manufacturer. It is further assumed that lubrication would be conducted by the user every three months with the aid of a lubrication kit supplied by the manufacturer. Lubrication of the compressor drive would be accomplished from outside the unit, but would require the user to open the circuit breaker at the panel board and open a vacuum breaker located on the unit. In addition, the user is required to clean the lint filter periodically - and, not more than once per year dump the concentrated liquor to the sewer or perhaps to a catch basin for pick up by a waste disposal service. Electrical power costs are not included in the operating costs since these costs are essentially the same as an equivalent capacity electrical water heater.

A useful life of 20 years and an 8% interest rate were assumed to estimate the "actual" annual average cost - because this type of unit must be designed to achieve a long useful life, and the current prime rate is near 8%. Thus, with an annual maintenance cost of $100, the total annual cost ranges from $999 to $620. Since these could be lowered if the unit was redesigned, they are considered to be the maximum cost of owning and operating a household size Recycler/Heater.

## Water and Sewer Costs

Assuming that the water recovery appliance operates 20 hours per day, 7 days per week the total volume of water recovered is 22.7 liters/hour X 140 hours/week, or 3180 liters/week, or an average of 165,360 liters (584 cubic feet) per year. The costs to the residential user for this amount of water in different metropolitan areas across the country are shown in Table 17. These costs include the commodity charge for metered water and an equal sewer charge, and are based on a monthly billing rate. They are an indication of the cost variations between areas served by most municipal water utilities. The "outside city" or suburban water and sewer costs are estimated to be double the amounts determined for "within city" costs - because most suburban waters must be "softened", or transported over longer distances. As an example of perhaps the highest cost of water in the United States, residents in Alaska outside the city limits of Fairbanks and Anchorage pay as high as $0.05 per gallon ($0.013 per liter).* Therefore, the cost of 165,360 liters per year to these users would be over $2,100 per year; these residents, of course, have learned to conserve water as much as possible.

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* H. J. Coutts, Personal Communication, Artic Environmental Research Lab., EPA, College Alaska.

## Table 17 TYPICAL WATER AND SEWER COSTS

| Location & Reference | Within City | Outside City |
|---|---|---|
| New Haven, Connecticut<br>New Haven Water Company Rate Schedule | $ 73.48 | $ 146.96 |
| Oakland, California<br>Dallas Water Utilities Survey, 1974 | 81.64 | 163.28 |
| San Diego, California<br>Dallas Water Utilities Survey, 1974 | 83.06 | 166.12 |
| Fort Worth, Texas<br>Dallas Water Utilities Survey, 1974 | 74.72 | 149.44 |
| Indianapolis, Indiana<br>Dallas Water Utilities Survey, 1974 | 94.48 | 188.96 |
| Nashville, Tennessee<br>Dallas Water Utilities Survey, 1974 | 89.12 | 178.24 |
| Kansas City, Kansas<br>City of Kansas City Rate Schedule | 46.64 | 93.28 |
| Chicago, Illinois<br>Rate Schedules | 33.12 | 66.24 |

## Potential Demand

Comparison of Tables 16 and 17 indicates that even if 1,000,000 Recycler/Heaters were mass produced each year they would not be economical to use in typical metropolitan areas. However, if the unit was redesigned to reduce the total annual cost by a factor of 4 or more, the purchase of a Recycler/Heater could be justified by homeowners in most suburban areas. Consequently, it is recommended that the development of a low-cost design be considered.

The developed Recycler/Heater, with a few minor improvements, is currently economical to use in Alaska suburban homes - even if it is produced at the rate of one unit per year. Thus, it is recommended that one of these units be evaluated in a suburban home in Alaska. Military installations where water and/or sewage must be transported by vehicles can also justify the use of the current design.

# SECTION IX

# APPENDICES

## Design Calculations

As stated in Section IV of this report, stepwise numerical computations were performed in order to find the power requirements for the processor as a function of evaporator temperature, $T_1$. These calculations were carried out in one-degree increments in the temperature range of 152°F to 160°F. All the numerical results are presented in tables A-1, A-2, and A-3.

Table A-1 shows the variations in the recycle flow rate requirements, $\dot{\omega}'$. It is seen that $\dot{\omega}'$ must increase as $T_1$ increases in order to maintain the flash evaporation process recovery rate, $\dot{\omega}$, constant at 50.13 lb/hr (6 gph).

In Table A-2 the compressor shaft horsepower requirements, $\dot{W}_s$, are given. As temperature $T_1$ increases the power decreases since both the volumetric flow, $v_2\dot{\omega}$, and the pressure rise, $\Delta p$, decrease. The shaft speed, N, also decreases with decreasing temperature due to decreasing specific volume, $v_1$, and slippage, S. It is noted that for these computations it was convenient to express equation (4) in Section IV in the following form.

$$\dot{W}_s = \frac{0.293\, C_p (T_2 - T_1)\dot{\omega}}{\eta_v \eta_i}\left[\text{watts}\right] = \frac{0.011\,(\text{CFM})\,\Delta p}{\eta_v \eta_i}\left[\text{HP}\right] \qquad \text{(A1)}$$

Table A-3, which gives the power requirements for the recycle pump, is a solution of equation (8) in Section IV. The determination of the condenser coil pressure drop, $\Delta p'$, requires the solution of the heat transfer relationships presented in Figure 7 of Section IV in order to determine the coil length, L. Then the total pressure drop is found by use of the Darcy formula for smooth tubes - namely,

$$\Delta p' = (\Delta p')_{100} \times L = 0.129\,\frac{f V^2}{v' D_i} \times L \qquad \text{(A2)}$$

where $(\Delta p')_{100}$ is the pressure drop per 100 feet of tubing. For smooth tubes the friction factor, $f$, is a function of the

Table A-1 RECYCLE FLOW REQUIREMENTS*

| $T_1$ (°F) | $P_1$ (psi) | v ($ft^3$/lb) | $h_f$ (Btu/lb) | $h_1$ (Btu/lb) | $h_1-h_f$ (Btu/lb) | $\frac{h_f'-h_f}{h_1-h_f}$ | $\dot{\omega}'$ (lb/hr) |
|---|---|---|---|---|---|---|---|
| 152 | 3.811 | 92.68 | 119.89 | 1126.9 | 1007.01 | 0.0119 | 4213 |
| 153 | 4.003 | 90.57 | 120.89 | 1127.3 | 1006.40 | 0.0109 | 4599 |
| 154 | 4.102 | 88.52 | 121.89 | 1127.7 | 1005.81 | 0.0099 | 5064 |
| 155 | 4.203 | 86.52 | 122.89 | 1128.1 | 1005.21 | 0.0090 | 5570 |
| 156 | 4.306 | 84.58 | 123.89 | 1128.6 | 1004.71 | 0.0080 | 6266 |
| 157 | 4.411 | 82.69 | 124.89 | 1129.0 | 1004.11 | 0.0070 | 7161 |
| 158 | 4.519 | 80.84 | 125.89 | 1129.4 | 1003.51 | 0.0060 | 8355 |
| 159 | 4.629 | 79.04 | 126.89 | 1129.8 | 1022.91 | 0.0050 | 10026 |
| 160 | 4.741 | 77.29 | 127.89 | 1130.2 | 1002.31 | 0.0040 | 12533 |

* $\dot{\omega}$ = 50.13 lb/hr; $T_3$ = 165°F; $T_e$ = 164°F; $h_f'$ = 131.89 Btu/lb.

Table A-2 COMPRESSOR POWER REQUIREMENTS*

| $T_1$ ($^oF$) | $v_1 \dot{\omega}/60$ ($ft^3$/min | M (rpm) | S (rpm) | M+S (rpm) | $\Delta P$ (psi) | Power (hp) |
|---|---|---|---|---|---|---|
| 152 | 77.4 | 2345 | 1369 | 3714 | 1.524 | 1.30 |
| 153 | 75.7 | 2294 | 1228 | 3522 | 1.332 | 1.20 |
| 154 | 74.0 | 2242 | 1202 | 3444 | 1.233 | 1.00 |
| 155 | 72.3 | 2191 | 1136 | 3327 | 1.132 | 0.90 |
| 156 | 70.7 | 2142 | 1072 | 3214 | 1.029 | 0.80 |
| 157 | 69.1 | 2094 | 1005 | 3099 | 0.924 | 0.70 |
| 158 | 67.5 | 2030 | 934 | 2964 | 0.816 | 0.61 |
| 159 | 66.0 | 2000 | 859 | 2859 | 0.706 | 0.51 |
| 160 | 64.6 | 1958 | 779 | 2737 | 0.594 | 0.42 |

* $D = 0.033\ ft^3/rev$; $K = 386$; $\gamma = 1.32$; $P_2 = 5.335$ psi; $\eta_v \eta_i = 0.40$

### Table A-3 PUMP POWER REQUIREMENTS*

| $T_1$ | $V_1$ | $N_{Re}$ | $f$ | $\Delta P_{100}$ | $\Delta T_m$ | $\theta_{ln}$ | $H_v$ | $H_\ell$ | $U$ | $L$ | $\Delta P'$ | Power |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (°F) | (fps) | $\times 10^{-3}$ | $\times 10^{3}$ | (psi) | (°F) | | (Btu/hr-ft$^2$-°F) | | | (ft) | (psi) | (hp) |
| 152 | 7.74 | 101.7 | 17.7 | 12.87 | 7.0 | 4.7 | 2678 | 2282 | 1206 | 45.3 | 5.8 | 0.057 |
| 153 | 8.43 | 110.8 | 17.5 | 15.10 | 6.5 | 4.4 | 2840 | 2450 | 1287 | 44.8 | 6.8 | 0.073 |
| 154 | 9.28 | 121.9 | 17.2 | 17.98 | 6.0 | 4.2 | 2884 | 2656 | 1348 | 45.1 | 8.1 | 0.096 |
| 155 | 10.31 | 135.5 | 17.0 | 21.94 | 5.5 | 3.9 | 2972 | 2889 | 1428 | 45.7 | 10.0 | 0.130 |
| 156 | 11.59 | 152.3 | 16.5 | 26.91 | 5.0 | 3.6 | 3066 | 3186 | 1520 | 46.1 | 12.0 | 0.180 |
| 157 | 13.23 | 173.8 | 16.0 | 33.99 | 4.5 | 3.4 | 3178 | 3558 | 1629 | 46.5 | 16.0 | 0.270 |
| 158 | 15.43 | 202.8 | 15.5 | 44.80 | 4.0 | 3.1 | 3302 | 4041 | 1761 | 47.1 | 21.0 | 0.410 |
| 159 | 18.50 | 243.1 | 15.0 | 62.32 | 3.5 | 2.8 | 3440 | 4678 | 1912 | 47.9 | 30.0 | 0.700 |
| 160 | 23.12 | 303.8 | 14.3 | 92.80 | 3.0 | 2.5 | 3650 | 5625 | 2128 | 48.3 | 45.0 | 1.300 |

* $D_o$ = 0.0625 ft; $D_i$ = 0.0555 ft; $v'$ = 0.016 ft$^3$/lb; $\eta'$ = 0.5; k/t = 55866 Btu/hr-ft$^2$-°F

Reynolds Number, $N_{Re}$, only, and can be obtained from the Moody Diagram for a Reynolds Number defined by the flow velocity, V, and inside tube diameter, $D_i$ .

## Design Details

The detail design of the Wash Water Recycler and Heater is described by the following list of assembly and detail drawings, and parts lists. (On file with EPA and Life Systems, Inc., Cleveland, OH.)

| | |
|---|---|
| 14958-3108-E-100 | Recycler/Heater Assembly |
| -E-114 | Processor Assembly |
| -E-113 | Weldment |
| -E-112 | Storage Tank |
| -R-106 | Evaporator Tank |
| -R-100 | Condenser Tank |
| -D-109 | Flanged Head |
| -R-101 | Condenser Cover Plate |
| -D-102 | Cover Plate Channel |
| -B-103 | Support Brackets |
| -B-104 | Channel Gasket |
| -B-105 | Cover Plate Gasket |
| -B-107 | Flange Gasket |
| -R-108 | Condenser Tubing Assembly |
| -C-110 | Tubing Support Brackets |
| -D-111 | Spray Manifold Assembly |
| -E-115 | Insulation Assembly |
| -C-117 | Control Schematic |
| -C-200 | Relief Valve Assembly |
| PL-100 | Parts List, Recycler/Heater Assembly |
| PL-114 | Parts List, Processor Assembly |
| PL-200 | Parts List, Relief Valve |

### Evaporator Tank

The evaporator tank weldment design is shown in drawing #3108-R-106. The shell is constructed of 10 gauge (.1345 inches) low-carbon, hot-rolled steel sheet, and has an ASME Code* allowable external working pressure of 11 psi.

In the evaporator the liquor from the condenser coil is transferred to the spray manifold assembly. The flow exits the coil through a 3/4-inch pipe coupling welded to the top of the condenser cover plate. Then it splits into two paths via 1/2-inch pipe sections, 180° apart, which connect to the spray manifold concentrically within the annulus formed by the condenser and evaporator shells. In the spray manifold the flow from each pipe feeds three equally spaced spray nozzels which have an orifice diameter of 0.209 inches (0.53 cm). The jets are directed downward approximately 75 degrees from the vertical, and the spray angle is approximately 105 degrees. Thus a full curtain is formed across the evaporator above the liquid level.

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* ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 (see Figure USC-28.1 for a cylinder length to outside diameter ratio of 1.98, and a outside diameter to thickness ratio of 180.), 1974.

The evaporator shell contains nine weld-on pipe couplings which are identified by numbered bubbles in the weldment drawing #3108-R-106. The functions of these couplings are listed as follows:

| Coupling No. | Size | Function |
|---|---|---|
| 1 | 1/4-18 NPT | Connection for installing thermocouple wires, if desired. |
| 2 | " | Vacuum switch mounting |
| 3 | " | Vacuum gauge connection for evaporator pressure reading. |
| 4 | " | Connection for purging non-condensible gases from condenser shell. |
| 5 | 1/2-14 NPT | Connection for 115 VAC power lines to compressor motor. |
| 6 | 1-11½ NPT | Connection for recycle liquor into condenser coil. |
| 7 | 2½-8 NPT | Liquid level switch mounting |
| 8 | 1/2-14 NPT | Connection for feed line |
| 9 | 2-11½ NPT | Connection for suction line to recycle pump. |

### Condenser Tank

The condenser tank weldment design is shown in drawing #3108-R-100. The tank consists of the condenser shell in which the condenser coil is mounted, and a standard schedule 40, 4-inch pipe section which is welded to the bottom of the shell. The condenser shell is secured concentrically within the evaporator shell via a weldment of the pipe support column to the bottom head of the evaporator tank. This weldment insures complete isolation of the condenser and evaporator sections. The pipe section also serves to transfer the condensate or product water out of the processor.

The condenser shell is constructed of 10-gauge, low-carbon steel. The shell is closed at the top by a 1/4-inch thick steel plate which bolts to a rolled-steel, inside-ring flange welded to the shell. Design calculations used to confirm the condenser shell thickness, cover plate thickness, and flange dimensions were based on a maximum internal pressure of 2 psi which is controlled by a pressure relief valve in the cover plate. Since the design working pressure is 0.92 psi, the relief valve is primarily required to prevent overloading of the compressor motor during transient or start-up conditions.

The compressor drive assembly is mounted directly to the condenser cover plate. The outlet of the compressor is sealed from the evaporator by a rubber sleeve which is compressed into a tappered hole in the cover plate. This sleeve arrangement also serves as a flexible joint to relieve compressor housing stresses. Vapor is transferred from the compressor outlet to the bottom of the condenser shell via the cover plate channel and the condenser coil support pipe.

Condenser Coil

The condenser coil design is shown in drawing #3108-R-108. The assembly consists of a central 2-inch brass pipe to which two tiers of 3/4-inch diameter, spiral-wound copper coils are horizontally fastened via three copper support brackets. The brackets are brazed to the coils and serve as radial and axial spacers. This method of assembly provides a rigid support while minimizing thermally induced stresses in the tubing.

Inlet and outlet connections to the heat exchanger are made with steel CPV (Combination Pump Valve Company) fittings which are brazed to the open ends of the coils.

Storage Tank

The storage tank weldment design is shown in drawing #3108-E-112. The shell is constructed of 10-gauge, low-carbon, hot-rolled steel sheet and has a design internal working pressure of 76 psi, which is allowable according to the ASME Code formula governing the head design. For a torispherical head, the maximum allowable working pressure is given by

$$P = \frac{SEt}{0.885L + 0.1t} \tag{B1}$$

where: P = design pressure, psi
S = maximum allowable stress, 12000 psi
E = joint efficiency, 1
t = wall thickness, .1345 inches
L = crown radius, 24 inches

No corrosion allowance was used in this calculation.

The storage tank shell contains weld-on fittings which are identified by numbered bubbles in the weldment drawing #3108-E-112. The functions of these couplings are listed as follows:

| Coupling No. | Size | Function |
|---|---|---|
| 1 | ½-14 NPT | Condensate inlet |
| 2 | " | Product water outlet |
| 3 | 1-11½ NPT | Connection for heater/thermostat |
| 4 | ¼-18 NPT | Connection for pressure switch |
| 5 | ½-14 NPT | Vent connection |
| 6 | ¼-18 NPT | Temperature gauge connections |
| 7 | ½-14 NPT | Pressure/temperature relief valve connection, or vent connection |

### Weldment Assembly

The evaporator and storage tanks are welded into an integral assembly according to the design shown in drawing #3108-E-113. The tank center lines are three feet apart; this space forms the sump tank which is open at the top. Standard light-steel channels welded vertically at the front and rear of each tank form the support legs for the assembly and a frame for securing the insulation jacket. Additional channels at the bottom of the structure form a rectangular frame to support the recycle pump and product water pump assemblies. The total structure weight is approximately 600 pounds (272 kg).

### Insulation

The design of the insulation assembly is shown in drawing #3108-E-115. Insulation is accomplished by twelve 24x48x2 inch insulation panels which cover the sides and removable door of the Recycler/Heater unit. Two additional panels are required to cover the top of the unit. These glass fiber materials (Johns-Manville Type 814) have a thermal conductivity of .020 Btu per hr., per ft$^2$, per $^{\circ}$F at a mean temperature of 110$^{\circ}$F. The side and rear insulation panels are cemented to thin (.060 inch) white fiber glass-reinforced plastic sheets which are riveted to the Recycler/Heater structure to form a smooth jacket all-around the unit. The front panels are also cemented to a thin fiber glass sheet. This sheet in turn is cemented to a separate rectangular fiber glass channel frame which forms a quick access full length removable door at the front of the unit.

## Analytical Methods

All the analytical methods pertaining to the water quality tests described in Section VI of this report are listed as follows:

### CHEMTRIC Analyses

A. Total Residue: As per Standard Methods for the Examination of Water and Wastewater, 12th edition (1965), AWWA-APHA-WPCF, pages 534-535.

B. COD: As per "Standard Methods", 13th edition (1971), pages 495-499.

C. pH: As per "Standard Methods", 13th edition (1971), pages 276-280.

D. Specific Resistance: As per "Standard Methods" 13th edition (1971), pages 323-327. Also YSI Model 31 Conductivity Bridge Instruction Manual.

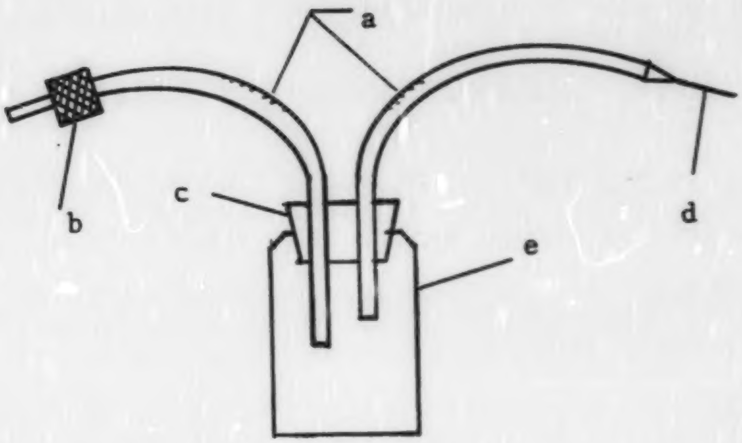
E. Turbidity: As per "Standard Methods", 13th edition (1971), pages 350-353. Also Hach Laboratory Turbidity Meter Model 2100A Instruction Manual #1000-1-4-72-2 ed.

F. Sterility: The plastic bottle shown on the next page is sterilized with the screw cap loosley in place by autoclaving for 15 minutes at 250°F. The bottle is stored at 2°C-8°C until used. The remaining sampling apparatus is assembled, sealed in a paper bag and sterilized as above. In addition a paper cover is placed over the needle prior to sterilization.

Sampling is accomplished by quickly removing the cork assembly from the paper bag and inserting the cork in the sample bottle. The needle is inserted into the appropriate septum of the Recycler/Heater. Just prior to needle insertion the septum is swabbed with iodine saturated cotton to insure sterility.

Fluid Thioglycolate Medium (Scientific Products, Cat. No. 21195) is used to determine sample sterility. One ml of sample is aseptically pipetted into a test tube of thioglycolate medium; the tube is incubated at 35°C for 48 hrs. Standard sterility techniques are used. Three tubes are innoculated for each sample evaluated.

The results are recorded as positive or negative on the basis of growth observed in the test tubes. If growth is observed in all three tubes the result is recorded as positive. If less than three tubes show growth the results are recorded as negative.



EQUIPMENT:

a. Rubber tubing
b. Bacteriological filter
c. Rubber stopper
d. Needle, hollow
e. Bottle, 500ml polypropylene
f. Cotton swabs
g. Laboratory incubator
h. Fluid Thioglycolate
i. Iodine solution
j. Laboratory autoclave
k. Pipettes, one ml

Subcontracted Analyses

The tests subcontracted to the Nalco Chemical Company, Analytical Services Division, were performed as follows.

A. Metals: (Barium, Cadmium, Chromium, Copper, Iron, Lead, Magnesium, Silver, Selenium): as per Methods for Chemical Analysis of Water and Wastes, 1971, EPA Manual, pages 78-155.

B. Ammonia: As per EPA Manual, pages 175-181.

C. Nitrate: As per EPA Manual, pages 201-214.

D. Cyanide: As per EPA Manual, pages 40-49.

E. Arsenic: As per EPA Manual, pages 9-10.

F. Phenols: As per EPA Manual, pages 241-248.

G. MBAS: As per EPA Manual, pages 157-158.

H. Floride: As per Federal Register, Vol, 39, Part 2, No. 206, pages 37, 730 to 37, 741.

I. TOC: As per gas chromatography using Beckman TOC Analyzer.

J. Chloride: As per "Standard Methods", 13th edition (1971), page 96.

K. Sulfate: As per "Standard Methods", 13th edition (1971), pages 334-336. Also, ASTM Standard (1973) Part 23, Water: Atmospheric Analysis, page 425.

## Installation, Operation & Maintenance

The following instructions apply to the Recycler/Heater Units shipped to (1) U.S. Army Medical Bioengineering Laboratory of Fort Detrick, and (2) the Naval Ships R&D Center at Annapolis.

### Installation

The schematic presented on the next page illustrates the arrangement of components on the Recycler/Heater, and the required connections. In addition the schematic shows the gauges and the replacement pumps which are recommended for laboratory testing. The schematic arrangement of the electrical controls is presented in figure A-1.

### Preliminary

A. Remove the cabinet door on Recycler/Heater and inspect all components for damage and loose electrical connections. Call Chemtric if any damage or loose connections are found.

B. Remove the flanged head on the processor tank and inspect the compressor drive for damage and loose connections or fasteners. The flanged head is removed by removing the top insulation panel and the upper section of the side insulation panel. This section has four rivets at the front and back side which must be drilled out with a 3/16-inch drill. Replacement of the panel requires eight new rivets. Replace the flanged head with a new gasket coated on both sides with silicone vacuum grease.

C. Install clear flexible tygon tubing level gauges on sump and storage tanks as shown in the installation schematic. These tubes can be taped to the outside of the insulation jacket.

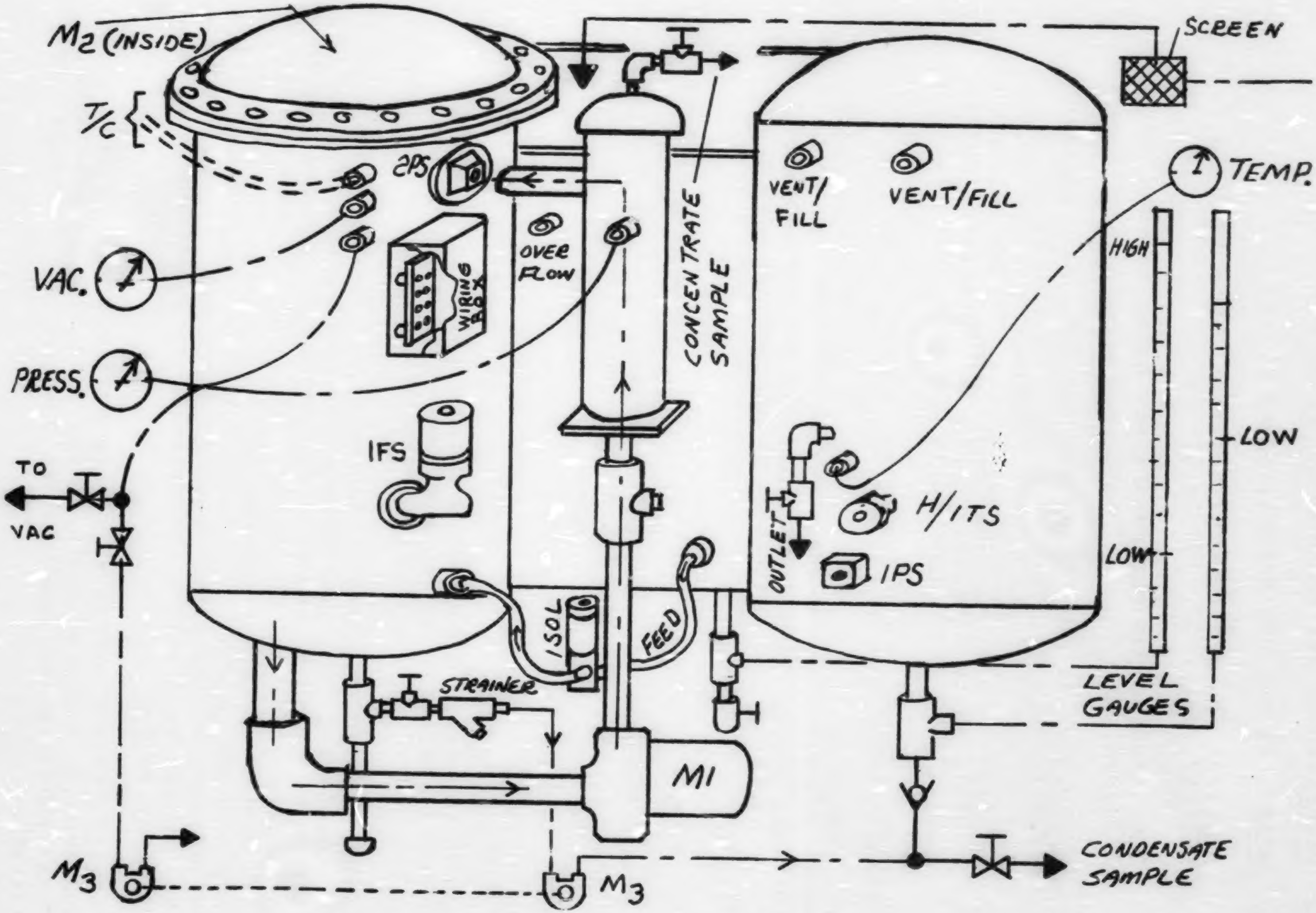

M2 (INSIDE)
T/C
2PS
VAC.
PRESS.
TO VAC
OVER FLOW
WIRING BOX
IFS
ISOL
FEED
STRAINER
M3
M3
M1
CONCENTRATE SAMPLE
SCREEN
VENT/FILL
VENT/FILL
TEMP.
HIGH
LOW
LOW
OUTLET
H/ITS
IPS
LEVEL GAUGES
CONDENSATE SAMPLE

Figure A-1 INSTALLATION SCHEMATIC

D. Remove the 20-mesh screen in the Y-strainer and clean if necessary. Close the strainer valve.

E. Close the concentrate sample valve.

F. Install the peristaltic pump. Note that this is a double-head single-motor pump. Connect the tubing to the heads as shown in Figure A-1, and electrically in Figure A-2. The peristaltic pump is located outside the insulation jacket close to the unit.

G. Connect a portable vacuum pump into the purge line at point shown in Figure A-1. Note that the vacuum pump is only used for initial evacuation of the processor tank, and should be electrically connected to a separate power source.

H. Install wall mounted fusible (30 ampere slow-blow fuse) circuit breaker with manual control; install push button switch 1PB in close vicinity to the unit. Make interconnection wiring as per figure A-2. The main power line from the circuit breaker is connected directly to the terminal strip located in the wiring box mounted on the processor tank; terminals 11 & 12 on unit at Fort Detrick, terminals 7 & 8 at Annapolis. Wiring to push button switch 1PB can come directly from the wiring box terminal strip. Check that jumper wires are in place in pressure switch 1PS. Place circuit breaker and push button switch in "off" position.

Filling & Heating

A. Fill the storage tank with tap water to the outlet line level noted in Figure A-1; mark this position on the liquid level gauge.

B. Fill the sump tank with tap water to the overflow line level noted in Figure A-1; mark this position on the liquid level gauge.

C. Close the circuit breaker. The storage tank heater will then come "on", and feed valve will "open".

D. Start the vacuum pump and begin to evacuate the processor tank; as the processor vacuum increases the feed rate increases due to the higher $\Delta$P. Evacuate to 26 inches HG vacuum, and turn-off vacuum pump and close vacuum valve.

E. The processor is filled when the feed valve snaps closed. During filling observe the sight gauge on sump tank to insure that water level does not go below feed line level; mark this position on liquid level gauge. Since the processor tank holds 33 gallons and the feed sump

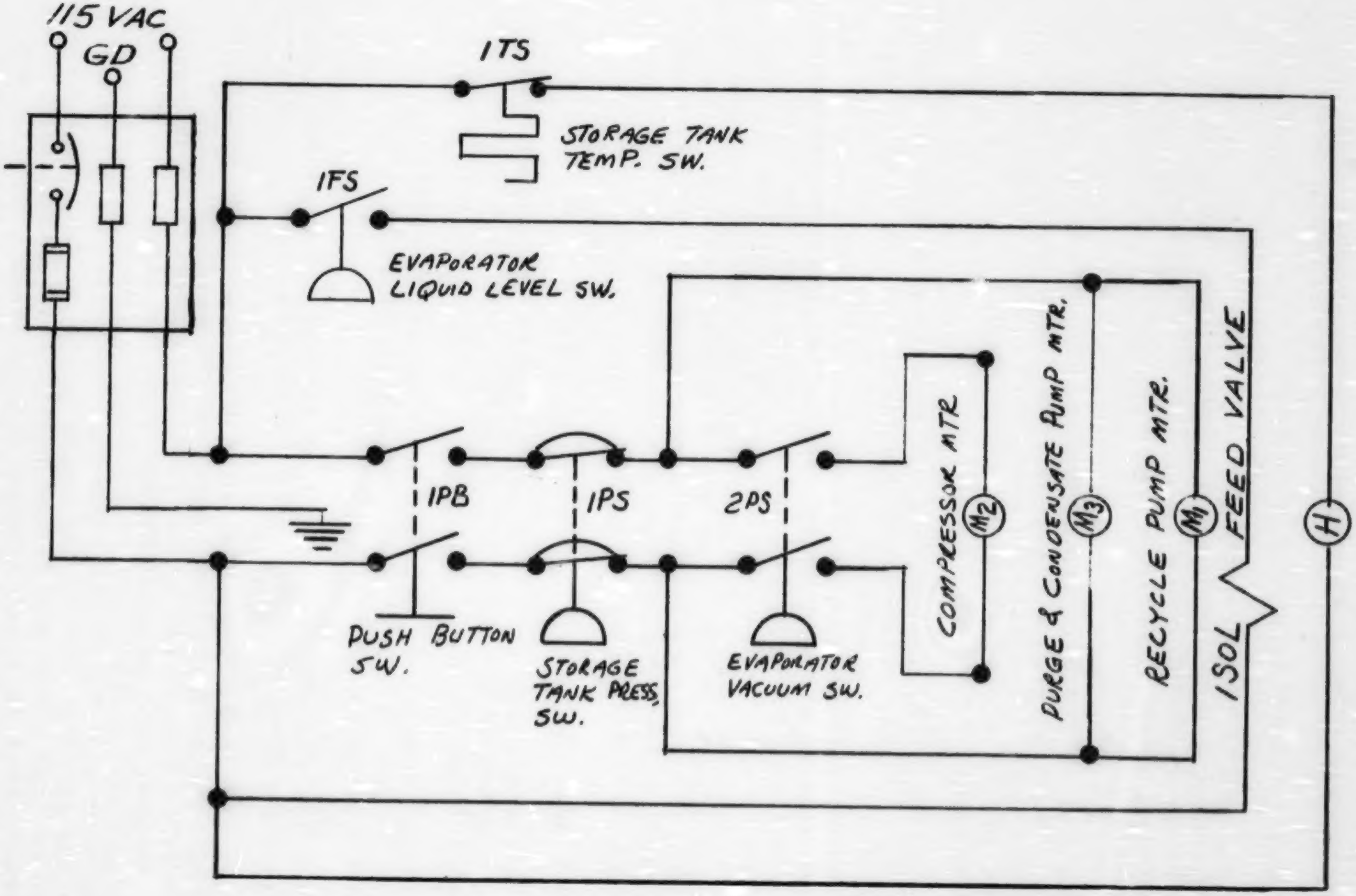

115 VAC
GD
1TS
STORAGE TANK TEMP. SW.
1FS
EVAPORATOR LIQUID LEVEL SW.
1PB
1PS
2PS
PUSH BUTTON SW.
STORAGE TANK PRESS. SW.
EVAPORATOR VACUUM SW.
COMPRESSOR MTR
M2
PURGE & CONDENSATE PUMP MTR.
M3
RECYCLE PUMP MTR.
M1
1SOL FEED VALVE
H

Figure A-2 CONTROL SCHEMATIC

holds 29 gallons, additional filling is required.

F. With the push button switch in the "off" position, remove cover on vacuum switch 2PS and remove compressor motor wire located at far right terminal facing switch.

G. Check operation of the recycle, and purge and condensate pumps by placing push button switch 1PB in "start" position; recycle pump, purge pump, and condensate pump should come "on". Note that the feed valve will open to allow additional fluid into the processor to fill the recycle line. The recycle pump pressure should be approximately 34 psig when the processor is at atmospheric pressure, and approximately 20 psig when the processor is at 26 inches HG. Allow recycle pump to run for several hours to deaerate the fresh feed stock. (Note: Check peristaltic pumps for proper pumping direction).

H. Depress push button switch 1PB to "off" position. Replace compressor motor wire in vacuum switch 2PS.

I. Close the insulated door and allow 16 hours for heat-up.

Start-Up

A. Check the vacuum gauge; vacuum should be approximately 23 inches HG after heat-up period.

B. Check the storage tank temperature; temperature should be 160°F.

C. Open the strainer valve.

D. Actuate push button switch 1PB; recycle pump, compressor, purge pump and condensate pump should come "on".

E. The processor is now operational; unit will automatically process water in feed sump, and store the processed water in storage tank.

F. The processor should be turned off or feed sump refilled when the liquid level in the sump is approximately three inches above the feed line level; mark this position on the liquid level gauge.

G. When the processor is turned "off" the heater remains on, unless the circuit breaker is opened, to maintain the stored water at pasteurization temperature.

Operation

Once the unit is initially evacuated via the use of a vacuum pump inserted into the purge line at the position shown in Figure A-1, the day-to-day operation is simply controlled by the push button switch 1PB. Before starting the unit each day it is important to observe the vacuum gauge and temperature gauge to insure that the heater in the storage tank is operative, and that the processor tank is at saturation pressure. The typical operational procedure is as follows.

A. Check the storage tank temperature; it should be in the range of 157 to 163°F.

B. Check the vacuum in processor tank; it should be 23 to 25 inches HG.

C. Fill the sump tank with wastewater to line marked on liquid level gauge - just below overflow line.

D. Depress push button switch 1PB to "start" position - to start the recycle pump, compressor, purge pump, and condensate pump.

E. Check the tubing in the peristaltic pumps. For maximum life of tubing, pull through a new section of tubing (while pump is running) every 10 hours of operation. When tubing takes a permanent set replace with new line. To replace tubing shut-off purge line valve and condensate line valve.

F. Maintain the sump tank level above "low" mark on level gauge - i.e., just above the feed line.

G. Maintain the storage tank level above "low" mark on level gauge - just above outlet line. This will insure that the storage tank heater is always immersed in liquid.

H. Remove recovered water from storage tank as necessary via the outlet line valve. Note that a vent hole is provided to prevent pressure build-up in the storage tank.

I. Check the compressor discharge temperature via the type "T" thermocouple provided. When this temperature exceeds approximately 200°F remove front door panel to stabilize the temperature. Replace the door when unit is shut-off.

J. Turn unit "off" as necessary by depressing push button switch 1PB to "stop" position.

K. Note that between runs the processor temperature will naturally decrease. Typically, for a 16 hour shut-down between runs the processor will cool approximately 20F degrees. This cooling will cause the absolute pressure to drop so that the next run always begins at a higher vacuum.

## Maintenance

The Recycler/Heater Units require the following periodic maintenance.

A. Replace the peristaltic pump tubing when it takes a permanent set - that is, it remains in a flattened position. Fifty feet of tubing, Cole-Parmer #6411-45 (0.1925 I.D. x 0.3920 O.D.) should last 750 operating hours - provided it is repositioned in the pump every 10 hours of operation.

B. Lubrication of the compressor drive should be checked every 500 hours of operation. Lubrication consists of:*
   (1) Compressor timing gears - use Chevron OC Turbine Oil #36.

   (2) Compressor bearings at drive end - use Chevron polyurea EP grease #2.

   (3) Compressor motor bearings(2) - use Chevron SR1 grease #2.

C. Remove condensate line strainer (20 mesh stainless steel screen) every 100 hours of operation and clean and blow-out with compressed air. Replace strainer using Loctite sealant/teflon (PS/T) on the strainer pipe fitting.

D. Remove lint strainer and clean periodically as required.

A maintenance manual and list of spare parts prepared by the manufacturer on the compressor, recycle pump, and condensate and purge pumps, are provided with each unit. Any repair work required on the compressor should be handled through Chemtric. The only replacement item in the recycle pump is the shaft seal. The seal number is P-2752; it can be obtained through Chemtric, or any Worthington Pump Distributor. A list of these distributors is furnished with each unit. Replacement parts for the peristaltic pumps are the sealed bearings in each head, which can be obtained directly from the Cole-Parmer Company. For replacement of bearings and seals in the compressor motor and recycle pump motor, these items can be ordered directly from the motor manufacturer according to the nameplate information on each motor.

All the control components - i.e., the storage tank temperature switch and heater (ITS), liquid level switch (IFS), evaporator vacuum switch (2PS), and solenoid feed valve (ISOL) -

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* See Bulletin RME-12 Sutorbilt, or Bulletin 37-3-602 Gardner-Denver Company, for complete compressor maintenance details.

should last the life of the unit. However, should any of these items need replacement or service contact the manufacturer according to the information presented below.

The heat exchanger and relief valve are items that should last the life of the unit. Should these items become defective such that a cleaning operation cannot correct, replacements can be obtained from Chemtric according to the part numbers #3108-C-200 Relief Valve, and #3108-R-108 Condenser Tubing Assembly.

Replacement Parts

Replaceable parts should be ordered from the respective manufacturers, using the information listed below.

Compressor Drive Assembly

A. Compressor: Sutorbilt Model 4L, Fuller Company, Compton, California - or the Gardner-Denver Company Model 2PDR, Quincy, Illinois.

B. Motor: (Gould Incorporated, Century Electric Division, St. Louis, Missouri) 3/4 HP, 3450 rpm, NEMA 56 frame, single phase, 60 HZ, 115 volt, ball bearing, TENV, continuous duty, rigid base for belt drive, type CP capacitor start CW rotation. Motor to have the following special features:

1. Class H insulation.
2. Capacitor and relay mounted outside of high ambient environment.
3. No conduit box - lead wires exit through rear end-bell (1/2-NPT Hole). Lead wire length - 10 inches.
4. Name plate not to be fastened to frame.

C. Belt: #AX31, Dayco Gold Label cog belt.

D. Drive Sheave: Bushing #1215, 5/8-bore; 3.4 PD pulley, Dodge dual-duty, taper-lock sheave.

E. Driven Sheave: Bushing #1615, 5/8-bore; 3.8 PD pulley, Dodge Dual-duty, taper-lock sheave.

F. Connector & Receptacle (motor power lines): #2004-505 receptacle, #E2004-512 connector, Cam-Lok Division, Empire Products Company, Cincinnati, Ohio.

G. Flange Gasket: #3108-B-107, Chemtric, Inc.

### Recycle Pump Assembly

A. Pump: Model D-520, 1-1/4 x 1 x 4, cast-iron construction, Noryl impeller, diameter 4 inches, John Crane Type 21 Mechanical Seal (Ni-Resist vs. carbon, Viton bellows), Worthington Pump International, Division of Worthington Corporation.

B. Motor: 1/3. 1/2. or 3/4 HP, 3450 rpm, NEMA 56J face frame; stainless steel threaded shaft, 5/8 dia, single phase 60 HZ, 115 vole, ball bearing, ODP or TEFC, continuous duty, CCW rotation. Order from Worthington Pump Division, or direct from a manufacturer of electric motors.

Note: Original motor has special Class F Insulation (thermal protective switch removed). Replacement motors with standard insulation must have thermal protection and require water cooling via a 1/4 O.D. copper coil wrapped around motor frame.

### Condensate and Purge Pumps

A. Pump Head (Purge): Masterflex tubing pump, Cole-Parmer #7015 standard-head steel-rotor assembly.

B. Pump Head (Condensate): Masterflex tubing pump, Cole-Parmer #7015-20 add-on head steel-rotor assembly.

C. Motor Drive: Masterflex fixed speed drive, 575 rpm, Cole-Parmer #7539, Fixed Speed MF Drive, 115 VAC, 60 HZ.

D. Tubing: Silicone tubing, 0.1925 "I.D. x 0.3920" O.D., Cole-Parmer #6411-45.

### Control Components

A. Storage Tank Heater/Thermostat (H/ITS): ARTM-2000, 2000 watts, 120 volts immersion heater with built-in thermostat, Chromalox.

B. Evaporator Vacuum Switch (2PS): Class 9016, Type GVG-1, Form R, Square-D-Company.

C. Evaporator Liquid Level Switch (1RS): Model TF-63, Type S-1 switch (SPST), NEMA 1 enclosure, 2-1/2-inch stainless steel float, 6-inch stem length, set for minimum differential, Magnetrol Int'l, Downers Grove, Ill.

D. Feed Valve (ISOL): Model PV-514-B2 Pinch Valve, 115 VAC, 60 HZ, Trombetta Corp., Milwaukee, Wisconsin.

E. Push Button Switch (1PB): Class 2510, Type MCG-1, 2-pole, NEMA size M-1, B-36 thermal element, Square-D-Company.